# Governor Frank Keating's

# Tar Creek Superfund Task Force

Water Quality Subcommittee

Task 1 Report

Surface & Ground Water Monitoring

July 26, 2000

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## Executive Summary

**The Water Quality Subcommittee respectfully provides the following findings:**

- Tar Creek's water quality does not meet the Habitat Limited Aquatic Community Use specified in Oklahoma's 1998 Water Quality Standards.
- Sources of acid mine water and metallic contaminants to Tar Creek include:
  - Discrete discharges of acid mine water
  - Leachate and run-off from chat piles
  - Stream sediments
  - Diffuse groundwater discharge primarily from the Boone Aquifer
- The quality of acid mine seepage water has improved and although the quantity of acid mine water seeping or flowing from identifiable locations (see page __) has remained unchanged, the concentrations of the contaminants has decreased.
- The acidity of Tar Creek's water has decreased, but data for metals and other water quality parameters indicate no improvement in water quality.
- Metals in sediments within streams and lakes to which Tar Creek is tributary may constitute a current or future threat to water quality.
- The Boone Aquifer is persuasively contaminated with acidic and metals contaminated water.
- Contaminant water in the Boone Aquifer is a continuing threat to uncontaminated water in the Roubidoux Aquifer, a sole source of drinking water.
- Drinking water supplies within the Tar Creek site have shown no test data that exceeds primary drinking water standards, but have displayed test data that exceeds secondary drinking water standards.
- Based on existing information and studies, additional data is required to identify, design, and implement potential treatment systems and/or other remedial measures to address acid mine drainage, surface water sources, and groundwater sources of contamination in the Tar Creek Superfund area.

**The Water Quality Subcommittee recommends the following actions to be implemented and considered:**

- ♦ Tar Creek Water Quality Sampling-The DEQ will extend the OWRB and USGS historical studies. The goal of this study will be to determine the current quality of the water and to provide additional data to help in the identification of trends.Quapaw Tribe of Oklahoma and USGS-These groups will be conducting monthly sampling of Spring River, Tar Creek, and Beaver Creek to determine the extent of possible contamination, through a cooperative agreement with EPA under the Clean Water Act Section 106.
- ♦ DEQ and USGS Groundwater Investigation-These groups will participate in a joint investigation of the groundwater in the Boone Chert formation to identify the age of the water so that appropriate remediation activities can be developed.
- ♦ OWRB BUMP Monitoring-The OWRB will monitor two locations on the Spring River and Neosho River previously sampled by the OSDH between 1979 and 1984. It will also assess water quality in Grand Lake to determine eutrophic state and trends, as well as document use support.
- ♦ Current monitoring programs of Spring River and Grand Lake should be strengthened and coordinated to acquire the quality data with a minimum of time and manpower extended.
- ♦ Oklahoma State Environmental Agencies should work cooperatively to develop a long-term water quality monitoring program to maximize limited monitoring resources.
- ♦ We recommend that fish be collected and analyzed to determine if fish flesh are contaminated by heavy metals and document the potential impact to human health.
- ♦ About three years of additional surface water monitoring data are required to identify, design, and implement potential treatment systems of the surface water in the Tar Creek area.

## Introduction

The Tar Creek Superfund Site is located in the northeastern portion of Ottawa County, Oklahoma. The site is a former lead and zinc mining area and is the Oklahoma portion of the Tri-State mining district of northeastern Oklahoma, southeastern Kansas, and southwestern Missouri. Mining began in Ottawa County in the early 1900's and continued until the 1960's. The Boone Formation was the source of the metal ore and is also an aquifer. As such the mining operations pumped large volumes of water from the mine workings until mining ceased at which time the aquifer and hence the mines, began refilling. As water filled the mines, the native sulfide minerals, which had been oxidized by exposure to air, dissolved, creating acid mine water. By 1979, water levels had increased to the point that the acid mine water began discharging at the surface from several locations, severely impacting Tar Creek.

In 1980 the Governor of the State of Oklahoma established the Tar Creek Task Force to investigate the discharges; the Oklahoma Water Resources Board (OWRB) was designated as the lead State Agency. In 1981, the site was proposed to the National Priorities List (NPL). The Environmental Protection Agency (EPA) provided funding to the State of Oklahoma to conduct a Remedial Investigation and Feasibility Study (RI/FS) through a cooperative Assistance Agreement with the Oklahoma State Department of Health (OSDH), the lead State Superfund Agency. OSDH contracted with OWRB to perform the investigations. The site was listed on the NPL in 1983, making the top ten sites in the nation.

EPA signed a Record of Decision (ROD) for the site on June 6, 1984. The ROD addressed two concerns: 1) the surface water degradation by the discharge of acid mine water; and 2) the threat of contamination of the Roubidoux Aquifer, the regional water supply, by downward migration of acid mine water from the overlying Boone Aquifer through abandoned wells connecting the two.

The remedy provided for the elimination or reduction of the discharge of acid mine water by preventing recharge of the Boone Aquifer. This would presumably lower the water levels as discharge continued, eventually eliminating the discharge. Recharge was to be prevented by utilizing diking and diversion structures (i.e., berms were constructed and plugs installed) to stop the surface water of Tar Creek from entering the two collapsed mine shafts in Kansas which were identified as the main inflow points. A mine shaft was plugged in Oklahoma and a berm was constructed to divert Lytle Creek away from possible inflow points. Additionally, the remedy called for preventing the downward migration of acid mine water into the Roubidoux Aquifer by plugging 66 abandoned wells. During remediation, an additional 17 wells were identified and plugged, bringing the total to 83 wells. Construction activities as described in the ROD were concluded on December 22, 1986.

After Action monitoring was initiated in 1987 with monitoring of surface water sites, acid mine water discharges, and mine water levels to assess the effectiveness of the diking and diversion work. To assess the effectiveness of the well plugging operations water samples from 21 deep Roubidoux wells located both inside and outside the mining area were collected and analyzed in 1991 and 1992. After Action Monitoring continues to assess if the Roubidoux Aquifer has been contaminated by the overlying acid mine water in the Boone with the following activities: 1) discrete sampling of five wells identified as being impacted by mine water, 2) with drilling and sampling of five new wells constructed using state of the art technology, and 3) through the review of water quality data obtained from public water supply system annual reports.

In April 1994 the EPA issued their first Five Year Review in which they reported: 1) the diversion and diking structures were operating as designed but acid mine water discharges continued unabated; 2) water level in the Boone is not statistically different indicating acid mine water discharging to Tar Creek has not been reduced; 3) the concentrations of metals in the acid mine water discharges appears to be reducing; 4) that stream water continues to be severely impacted; and since the downgraded water quality standards assigned to Tar Creek (in 1985 OWRB lowered the designated beneficial uses of Tar Creek to habitat limited aquatic community and secondary body contact recreation) are protective of human health, then no further remedial action is recommended for the surface water. In summary, the OU1 remedy was mostly ineffective in mitigating the environmental degradation of the surface waters of Tar Creek drainage Basin. Additionally, the 1994 Five Year Review recommended an investigation should be conducted to evaluate the impact of mining wastes i.e., chat piles and floatation ponds, on human health and the environment and whether additional remedial action is warranted. These types of wastes were not significantly investigated during the Tar Creek OU1 Remedial Investigation, as the focus at that time was on water quality.

Additional information on mining wastes on the land surface was provided by EPA Region 7 prior to the first Five Year Review of 1994. Investigations of the Cherokee County Superfund Site, which represents the Kansas portion of the Tri-State mining district, indicated that mining wastes in Kansas contain elevated concentrations of lead (as high as 13,000 ppm) and cadmium (as high a s 540 ppm). Also, the Indian Health Service informed EPA that 34% of the 192 Native American children tested had blood lead levels in excess of the 10 ug/dL standard.

From August 1994 through July 1995, EPA conducted sampling of soils in High Access Areas (e.g., day care centers, school yards, and playgrounds) and residential properties to determine the nature and extent of contamination of the residential areas of the site. This site assessment data was the basis for the Baseline Human Health Risk Assessment (BHHRA) issued in August 1996 and the Residential RI Report issued in January 1997.

The releases of heavy metal contamination associated with the mining wastes deposited on the surface of the ground (i.e., chat poles and floatation ponds) have been termed Operable Unit 2 (OU2). A second ROD was signed on August 27, 1997, which addresses the residential areas of OU2. Remedial actions of residential areas of OU2 began in June 1996 as a removal action and continued in January 1998 as a remedial action. Approximately 1,600 lead contaminated residential yards will be remediated. An additional 500 properties have been identified for remediation.

The BHHRA for residential areas identified lead in soil as the only site related chemical of concern and identified oral ingestion of lead contaminated soil as the only significant exposure pathway. It predicted 21 % of the children in Picher would have elevated Blood lead levels (above 190 ug/dL) and set the clean up level for lead at 500 ppm. A blood lead survey conducted in Picher in 1995 by the OSDH found a percentage of children with elevated blood lead levels similar to that predicted by the BLHHRA. Later surveys conducted in August 1996 and September 1996 found that 38.3 percent (31 of 81) of the children tested in Picher had blood lead concentrations exceeding 10 ug/dL, that 62.5 percent (10 of 16) of the children tested in

Cardin had blood lead concentrations exceeding 10 ug/dL (10 of 16), and that 13.4 percent (nine of 67) of the children tested in Quapaw had blood lead levels which exceeded 10 ug/dL. These are actual measured values of lead in children's blood and not just predictions. These findings contrast sharply with the statewide average blood lead concentration in children of 2 percent reported by OSDH. Preliminary data being gathered by the University of Oklahoma Health Sciences Center show that in conjunction with EPA's remediation efforts the percentage of children with elevated blood lead levels at the Site is beginning to decrease.

The EPA issued the second Five Year Review report in April 2000. It reported that although the environmental components of the Water Quality Standards are not being met (i.e., certain numerical and narrative water quality criteria including metals toxicity to aquatic life, pH, DO, and aesthetics are being violated), this does not pose a human health threat. The available data indicate: 1) levels of lead in sediments in Tar Creek, 2) metals and pH levels for dermal contact, 3) metals levels for ingestion of water while swimming, and 4) metals levels in fish flesh are generally below levels of concern for protection of human health. Since the criterion in the OU1 ROD for further remedial actions (i.e., human health risk not adequately mitigated) has not been triggered no further remedial action is recommended. The report did indicated additional monitoring may be needed in order to confirm that contamination levels have not worsened and stated that in the future EPA will review the need for updated monitoring of the contamination to Tar Creek for human health impacts.

In February 2000, a task force was created by Governor Frank Keating to investigate issues related to the Tar Creek Superfund Site in Ottawa County, Oklahoma. This report was prepared by the Water Quality Subcommittee and is being submitted to the Governor's Task Force. Active members of the Subcommittee include Earl Hatley (Co-Chair, Quapaw Tribe of Oklahoma), Glen Jones (Co-Chair, Oklahoma Department of Environmental Quality), Bill Andrews (United States Geological Survey), David Cates (Oklahoma Department of Environmental Quality), Kent Curtis (Inter-Tribal Environmental Council), J. Berton Fisher (Gardere and Wynne, L.L.P), Meredith Garvin (Quapaw Tribe of Oklahoma), Ron Jarman (Roberts/Schornick & Associates, Inc.), Gene Lilly (US Army Corp of Engineers), Bob Nairn (University of Oklahoma), Sharon Robbins (Oklahoma Department of Environmental Quality), John H. Roberts (U.S. Army Corps of Engineers), and Derek Smithee (Oklahoma Water Resources Board).

The Task Force designated two tasks to the Water Quality Subcommittee. The first duty assigned was compiling available data on water quality, determining what additional data is needed, and drafting a proposal outlining future necessary monitoring. This subcommittee will also compile information on treatment alternatives to remove contaminants; evaluate the feasibility of constructed wetlands, diversion techniques, methods of lowering the water table, and other alternatives; review the work conducted by the OWRB; draft a proposal for each alternative that includes a scope of work, timeline, resource needs, and potential sources of funding for the project; estimate the degree of water quality improvement; and measure resources for evaluating project effectiveness. This report will address the concerns of the first task. The focus will be on surface water and ground water, which are interrelated, but will be addressed separately.

## Chronological Monitoring Information

Historical data from the United States Geological Survey (USGS), EPA, OWRB, OSDH, and the Department of Environmental Quality (DEQ) have been collected and compiled into an Access database. This database contains raw data for the various water quality monitoring activities undertaken by these agencies in the Tar Creek Area. Copies of this data are provided on the computer disk attached at the end of the report. Due to discrepancies in sampling sites and the sampled parameters, additional analyses could not be undertaken on the data as one large data set. The comments made about the historical data in this report are based on the available historical monitoring data and consideration of the conclusions reached by the original sampling agencies

## Surface Water

*Streams and Lakes*

Based on a decrease in acidity of water, an evaluation of Tar Creek water quality data shows slow, incremental improvement in water quality within the time frame of the data. The other parameters showed no marked improvement. Although this improvement has not resulted in Tar Creek meeting it's Habitat Limited Aquatic Community Use specified in Oklahoma's 1998 Water Quality Standards (WQS) (OWRB, OAC 785:45), it does indicate that improvements are possible. Water quality information from the Spring River and Neosho River show elevated levels of metals, but data is insufficient to conduct rigorous statistical analyses. Spring River and parts of Grand Lake are currently listed on Oklahoma's 303(d) list as impaired by metals. A 1992 study of the impacts of heavy metals on Grand Lake showed the aquatic community to be little affected by these heavy metals. However, metals sediment contamination on Grand Lake remains a concern because as Grand Lake continues to become more eutrophic (resulting in reducing conditions and lower pH), metals in the sediment could once again become biologically available.

Available monitoring data indicate contaminant concentration in Tar Creek’s water column due to acid mine drainage and tailing pile leachate may be decreasing (Appendix B, Tables 1-8). However, the EPA notes in the Five-Year Review that water quality at downstream location sites 20 and 22 (see Appendix A, Figure A) indicates average constituent concentrations of many metals have increased. This may indicate an increased volume of discharge or dissolution of metals into the water column from stream bed sediments as mentioned above. However, it is difficult to explain why some constituents are decreasing while others are increasing. Additional monitoring is needed to confidently establish the existence of any surface water trends. Nonetheless, the Habitat Limited Aquatic Community beneficial use assigned to Tar Creek in Oklahoma’s WQS are not being met based upon currently available data. In particular, the statewide numerical criteria for the toxic substances cadmium, lead, and zinc, and the pH standard applicable to all fishery classifications, including the habitat-limited classification for Tar Creek, are not being met.

The OWRB Beneficial Use Monitoring Program (BUMP) monitors sites across Oklahoma (two sampling locations are on the Spring and Neosho Rivers). The intent of BUMP is to determine if the beneficial uses established for waters at the sites are being met, or are threatened or impaired. Data collected through BUMP and monitoring activities by other state agencies are then subjected to a standardized use support determination rule (called a Use Support Assessment

Protocol, or USAP), to document use support. Those waters with impaired beneficial uses are then listed on the Oklahoma 303(d) list of impaired waters and a Total Maximum Daily Load (TMDL) determination is initiated by DEQ. A TMDL quantifies the allowable contaminant load a water body can receive and still meet its beneficial uses.

The 1998 303(d) list specifies that Tar Creek, the Neosho River, Spring River and Grand Lake are all impaired by metals contamination. Monitoring is currently underway or proposed at all four water bodies by OWRB, Oklahoma Conservation Commission (OCC) and DEQ to confirm or refute these historical listings, but insufficient data is yet to be collected to satisfy the minimum data requirements for evaluation using the USAP.

Specific to Grand Lake, a cooperative study by Oklahoma State University and the OWRB found metals contamination of the sediments of Grand Lake - especially in the upper end near Twin Bridges. Results of this study, however, indicated that these metals were strongly sorbed to the sediments, and generally unavailable to impact human health and aquatic life. As Grand Lake continues to become more enriched through eutrophication, and strongly stratify during the summer, metals dissolution into the water column may begin to occur as previously stated.

No information could be found related to the impact of human health and the consumption of fish from within the basin. It is recognized that metals generally do not bioaccumulate metals in flesh as readily as other substances, particularly some pesticides; but a lack of monitoring data for zinc, lead and cadmium in fish flesh needs to be resolved (Appendix B, Tables 9-13). While WQS do provide human health protection criteria to allow for consumption of fish flesh, no standardized program currently exists in streams to evaluate lead and zinc concentrations. The lake sampling program is also inadequate.

*Acid Mine Discharges*
The available monitoring data indicates that overall the contaminant concentrations in the acid mine discharges have decreased since completion of initial remedial action (see Appendix B, Tables 14-18). Diversion and diking activity of the two major surface water inflow points was directed at reducing water inflow into the mines by approximately 75 percent, thereby eliminating or reducing acid mine discharges by a significant amount. Available monitoring data summarized in the EPA's 1994 Five-Year Review indicates that although the diversion and diking remedy was successful in preventing surface water inflow at these two locations, and although it has been successful in reducing the temporary rise in water in response to a given precipitation event, the remedy did not significantly reduce the surface discharges of acid mine water. (Note: The 2000 Five-Year Review is now available; however, the report is based on data obtained prior to the 1994 Review. No additional data was referenced in the 2000 Review.)

A 1983 study by the OWRB of the pollutants in the mine discharges indicated complex chemical responses occur during periods of inflow of oxygenated surface water. The negative correlation between iron and zinc concentrations in the major discharges supports the contention that continued acid mine water production may be occurring (OWRB, 1983).

The acid mine drainage has had a severe impact on Tar Creek, causing numerous exceedances of Oklahoma's WQS. As a result, the beneficial uses assigned to Tar Creek, including aesthetics and habitat limited aquatic community are not being achieved. Most of the biota in the creek have disappeared, and red stains caused by precipitation of ferric hydroxide dot the banks and bridge abutments.  Lead, zinc, cadmium, and iron from the mines contaminate the sediments in Tar Creek.  However, concentrations of these metals in both water and sediment near the mouth of Tar Creek are much less than further upstream.

The impact of Tar Creek on the aesthetics of Neosho River is evident from the red stains observed on cliffs and bridge abutments, although, except for zinc, no water quality criteria exceedances have been detected.  Within the scope of currently available data, the sediments of the Neosho River do not appear to be impacted by the acid mine contamination.  Within the scope of the data reviewed, no beneficial uses assigned to the Neosho River are impaired by the Tar Creek discharge.

*Sediment*
From the data it is observed that iron concentrations increased by an order of magnitude downstream from acid mine discharges (see Appendix B, Table 19). Above the discharges, the average iron concentration in the sediment is 4743 milligram/kilogram.  Below the discharges, the average concentration is 67,742 milligram/kilogram.  However, the data is erratic, and it is difficult to draw any conclusions as to the effects of the remediation.  The Health Affects Subcommittee of the initial Tar Creek Task Force concluded that sediments provide an effective long-term sink for metals and should effectively remove them from most biological processes. However, this conclusion is not supported by decisions and actions taken by the Department of Interior and the National Oceanographic and Atmospheric Agency in Natural Resource Damage Act claims in the United States.

*Tailings Piles*
The analytical results of the water sample collected at two tailing piles indicate waters flowing at these sites have a low pH and contain high concentrations of various heavy metals (see Appendix B, Tables 20-22).  These metals are leached out as a result of dissolution of sphalerite and galena by sulfuric acid that is formed by oxidation of pyrite and/or marcasite present in tailings piles. Of these metals, those that are less soluble will tend to precipitate after the pH is increased due to dilution.  The highly soluble metals, including zinc and cadmium, will remain in solution allowing them to reach the receiving streams.

3) The majority of the tailing piles in the Picher Mining Field are situated within the Tar Creek drainage basin.  The impact of acid mine drainage and tailings piles drainage has not been adequately independently assessed.  The adverse effects of tailings piles runoff on Tar Creek and its tributaries may be masked by the discharges of highly contaminated acid mine water from the flooded underground mines.  One study (OWRB, 1983) measured the leachate rate at two large chat piles and estimated the contaminant loading to Tar Creek from all tailings piles in the basin (Appendix B, Tables 15-17).  This study concluded that the metals loading to Tar Creek from tailings piles is insignificant compared to the loading contributed by underground mine discharges of acid mine water.  However, upon abatement of the mine discharges, mineralized tailings piles runoff to surface waters of the area could have a significant impact on aquatic organisms.

## Ground Water

*Hydrology and Geology*

Detailed descriptions of the geology and hydrology of the area are provided in the following paragraphs. Topography of the area is generally a relatively flat prairie. Elevations range from approximately 775 to 900 feet above mean sea level. The region is drained by Tar Creek and Lytle Creek, which combine and flow into the Neosho River. Bedrock in the Tar Creek area dips to the northwest at 15 to 20 feet per mile, with abrupt local variations caused by folding and faulting. In descending order the stratigraphy of the Tar Creek area and hydrogeologic significance (modified after McKnight and Fischer, 1970; and Reed, Schoff, and Branson, 1955) are as follows:

*Pennsylvanian age Strata*

**Krebs Group**: Consists of zero to 200 feet of gray to black fissile shale with some thin coal and sandstones and is present in the western and northwestern parts of Ottawa County but missing in the eastern portion of the county. Where present, the Krebbs Group forms a probable aquitard over the underlying Boone aquifer.

*Mississippian age Strata*

**Boone Formation**: Consists of 350 to 400 feet of bluish gray to light gray limestone and gray to white chert. The Boone Formation is also known as the Keokuk and Reed Springs Formations. The Oklahoma State Department of Health (OSDH) has mapped the Keokuk and Reed Springs Formations as a principle bedrock ground water resource in northeastern Oklahoma (Johnson, 1983). Ground water movement in the Boone Formation is primarily through fractures and solution cavities. The Boone Formation is also known as the Boone aquifer in northeastern Oklahoma and yields good quality water outside the mining area.

*Devonian and Mississippian age Strata*

**Chattanooga Shale**: consists of zero to 50 feet of black shale near the boundary between Devonian and Mississippian Periods. It is absent in most of the mining area. Where present, the Chattanooga Shale forms a probable aquitard restricting ground water movement between the overlying Boone aquifer and underlying Ordovician Strata. Deep wells in the area are usually uncased below the Chattanooga Shale.

*Ordovician age Strata*

**Cotter Dolomite**: consists of approximately 165 feet of dolomite and dolomitic limestones with oolitic, opalescent chert lenses and very fine grained sandy zones. The Cotter may contribute some water to deep wells, but its yield is unknown.

**Jefferson City Dolomite**: consists of 270 to 340 feet of dolomite with 10 to 50 percent brown chert. The rate at which groundwater can be produced from the Jefferson City Dolomite is unknown. Measured vertical permeability from core samples of the Cotter and Jefferson City Dolomites ranged between $3.1 \times 10^{-7}$ to $9.6 \times 10^{-9}$ cm/s (Encon, 1982). A few "healed" fractures (containing secondary deposits of carbonate mineral) were visually detected in the cores. These facts suggest that downward migration of mine water from the Boone to the Roubidoux through the intervening strata would be extremely slow.

**Roubidoux Formation**: consists of 105 to 180 feet of cherty dolomite with two or three layers of sandstone which are 15 to 30 feet thick. The Roubidoux Formation is a major producer of groundwater in the area and yields up to 600 gallons per minute. Most of the water is produced from a few relatively thin, highly permeable sandstone zones. The majority of the formation is lithologically very similar to the Cotter and Jefferson City Dolomites (having laboratory-measured porosity in the range of 0.025 to 0.09 and horizontal permeability from cores in the lower range mentioned in the paragraph above). The formation boundaries are very difficult to distinguish visually. The formation tops and bottoms may be determined using acid residual analyses where a grab sample of the formation is dissolved in acid, and the residual amount of silica defines the formation location.

The fact that the Boone Aquifer was contaminated by mining activities in the Tar Creek Superfund site has been documented by several episodes of sampling and analyses from mine shafts and cased holes to the Boone. The USGS conducted the first monitoring study in 1970's before acid mine water discharges began (Playton et al, 1980). The OWRB conducted a monitoring project in the 1980's where mine shafts and cased wells were sampled (Appendix B, Tables 23-25). The USGS and the OWRB again sampled mine shafts during the late 1980's (Appendix C, Table__). After the acid mine water began discharging the OWRB sampled the seeps for water quality and quantity of discharges. The water level in the Boone was also monitored on a daily basis during the 1970s and 1980s at the Blue Goose mine. These continuous water levels were exponentially correlated to total discharges measured only occasionally at the mine seeps (Parkhurst, 1985). The contaminant loading from the mine seeps was calculated as the average discharge times the average concentrations measurements, the number of discharge measurements being much greater than the concentration measurements (Appendix B, Tables 26-29).

Over ten years during the 1980s, the mine discharges have contributed more than 10 tons of cadmium, 9,000 tons of iron, 22 tons of lead, 1,700,000 tons of sulfate, and 13,000 tons of zinc to Tar Creek (OWRB, April 1991).The monitored mine discharges have only contributed about fifteen percent of the contaminant loading to Tar Creek. Even though only about half the known discharges were monitored it is evident that there are other sources of contaminant metals loading to Tar Creek. The OWRB (1991) concluded that either there are many unknown discharges of acid mine water, or much of the loading is due to surface sources (such as tailings pile leachate or resuspension). Since the metals loading from the mine tailings is relatively small (OWRB, 1983), the unknown loading sources may be discharges of acid mine water directly to groundwater feeding Tar Creek.

One major water quality concern is if the Roubidoux Aquifer, the primary source of drinking water in Ottawa County, has been contaminated by mining activities (Appendix B, Table 30-34). Studies conducted by the USGS determined that sulfate is the dominant anion in the mine waters, and iron and zinc are dominant cations indicative of contamination. Relatively large concentrations of cadmium, fluoride, and lead have been analyzed in some mine waters. Water in the Boone Aquifer has a tendency to move downward into the Roubidoux Aquifer because of a higher hydraulic head. The water can move through pores and fractures in rocks or by way of leaky well casings. About 100 wells were dug into the Roubidoux Aquifer to supply water for milling operations.  Two abandoned wells have displayed the movement of water flow from the Boone Aquifer to the Roubidoux Aquifer at a rate of up to 2 gallons/minute.  The EPA and DEQ continue to locate and plug any abandoned wells in the mining area that penetrate the Roubidoux Aquifer.

Public water supply wells in the cities of Commerce, Quapaw, and Picher have experienced problems due to mine water entering the wells through leaks in the casings or through the grout seals of the wells (Appendix D, Tar Creek PWS Summaries).  Between July 1981 and October 1982, two wells in Commerce had an increase in concentrations of sulfate, iron, zinc, and dissolved solids.  The water quality returned to acceptable limits for public supply after repairing the well casings.  A large iron concentration and low pH in a Quapaw well forced the abandonment and plugging of the water supply well in July 1981.

Past studies of the Roubidoux Aquifer in Picher between 1942 and 1951 have shown low concentrations of sulfate, usually only about 16 milligrams/liter.  However, samples taken from 1981 to 1982 revealed sulfate concentrations ranging from 47 to 92 milligrams/liter.  This dramatic rise suggests that the Roubidoux has been impacted by mine water.  A slight increase in iron concentration was also discovered in the samples, but no other trace elements showed increased concentrations.

The water quality of the Roubidoux wells at Picher and Quapaw is of significantly poorer quality than at Miami, Commerce, and Cardin with respect to total hardness, iron, sulfate, and zinc (Appendix B, Tables 30-34).  The mean concentration of iron exceeds the secondary drinking water standard at Picher and Quapaw.  Additional sampling was conducted on public water supply wells from the Roubidoux Aquifer located both inside and outside the mining area in 1991 and 1992.  This Phase I After Action Monitoring showed that five wells in Picher, Quapaw, and Commerce fail secondary drinking water standards.  However, these wells still meet primary drinking water standards including iron and sulfate.  Since the 1994 Review, discrete samples of Roubidoux water have been taken from the five public water supply wells that showed signs of being impacted by infiltration of acid mine water.  Tentative (incomplete) analysis indicates that acid mine water is infiltrating through inadequate casings, and this infiltration is the source of the contamination.  Water sampled from the new monitoring well in Picher, with state of the art casing, indicates the Roubidoux water quality is good, meeting both primary and secondary drinking water standards.

The most likely route by which the acid mine water could reach the Roubidoux Formation from the Boone Formation is by direct access through the active and abandoned deep wells. However, downward migration from the mine workings through the Chattanooga Shale(if present), Cotter Dolomite and Jefferson City Formations is possible, even though core testing showed intervening layers to have low permeability and that chemical reactions between the acid mine water and the aquifer material would tend to cause precipitation of the contaminant metals.

Decline of static water levels has been observed in the deep aquifers over the last 40 years.  Water levels are expected to continue to decline as long as pumping continues.  If the head differential is great enough, downward migration of contaminated water through fractures from the Boone into the Roubidoux is possible.

The EPA and the DEQ are currently conducting "After Action Monitoring" of the site to determine if the Remedial Actions conducted have been protective of human health, or if more corrective action is warranted. Future Superfund activities include continued ‘After Action Monitoring” and plugging of abandoned deep wells on the Roubidoux.

Under the completed and previously mentioned Phase I of the Tar Creek Ground Water Monitoring Project (TCGWMP) samples from eleven Roubidoux water supply wells inside the mining area and ten Roubidoux wells outside the mining area. Phase I wellhead sampling results prompted the DEQ to suspect that five of the wells inside the mining area are being impacted by acid mine water. These wells produce water with elevated concentrations of iron, zinc, and sulfate over background levels in the Roubidoux aquifer outside the mining area (DEQ Technical Memorandum, 1993). The DEQ and EPA concluded that the five municipal wells were producing water exceeding secondary drinking water standards for iron, sulfate and zinc, and that these wells were impacted by acid mine water.

Phase II of the TCGWMP is being conducted to determine if the poor quality of drinking water is due to acid mine water infiltrating directly into the Roubidoux aquifer from the Boone formation, or if the acid mine water is getting into the groundwater through the deteriorated casings in the municipal wells. Inflatable packers were set in four of the municipal wells, and a PVC casing was installed in the fifth well. In addition, a monitor well was completed in the Roubidoux aquifer. Discrete water samples from the five municipal wells and the monitor well continue to be collected, analyzed and evaluated.

The purpose of Phase II - **Supplemental** of the TCGWMP is to install four additional monitor wells in the Roubidoux aquifer for the collection of ground water samples. To establish representative Roubidoux monitoring sites, the wells will be constructed like typical public water supply wells of the area and may be used by the cities (Picher, Cardin, Quapaw, or Commerce) for drinking water supply should the water quality of the wells prove to be acceptable.

**Proposed and Recommended Monitoring Activity**

There are five initial monitoring activities already scheduled to be conducted during the Summer of 2000 to provide additional information so that appropriate decisions can be made regarding the quality and treatment of the surface and ground water in the Tar Creek Area These monitoring activities will be done cooperatively with other state and federal partners to reduce duplication. It will also be submitted to the Water Quality Monitoring Council for review and comment. These are as follows:

*Activity 1: Tar Creek Water Quality Sampling*

The DEQ has initiated steps to provide some additional monitoring to give an updated picture of water quality in the Tar Creek Basin. The complete work plan is attached as Appendix D. Previous field surveys of sixteen sediment and water collection sites in the Grand River Drainage Basin (consisting of Tar Creek, Beaver Creek, Neosho River, and Spring River) have been conducted by the USGS of the U.S. Department of Interior between 1983 and 1985. The DEQ will extend the OWRB and USGS historical studies. The goal of this study will be to determine the current quality of the water and to provide additional data to help in the identification of trends.

The DEQ has identified three additional sites that will also be used for sample collection and analysis. Historical data concerning monitored parameters, physical conditions, and chemical conditions of surface waters in the basin from the OSDH, OWRB, and DEQ will be used as baseline information. The sample collection and analysis project will attempt to determine water quality changes since the USGS study, identify trends for the changes, and establish Tar Creek's impact on water in Grand Lake. A Total Maximum Daily Load (TMDL) will be established using the data from the sixteen OWRB sites and the 3 additional sites added by the DEQ. The TMDL concerns the content of acid mine discharge in a stream. The amount of point and non-point contaminant load that can exist in a stream safely without harming the designated use of the stream will be determined.

High flow and low flow events from three sites will be monitored over the course of one year. The flow rates will be incorporated into the TMDL model and may provide clues and evaluate the source of metals within the basin. A statistically valid sampling plan to accurately quantify water quality in the Tar Creek Basin will be developed using the Data Quality Objectives (DQO) process. The initial samples will be tested for iron, lead, zinc, cadmium, and other metals. Any metals that occur in high quantities will be sampled monthly for the course of one year. Sediment and water samples will be collected from the Grand River Drainage Basin. It is believed that most metals in acid mine water will precipitate out of water and into Tar Creek sediments providing an effective long term sink for metals and effectively removing them from most biological processes.

*Activity 2: Quapaw Tribe of Oklahoma & USGS Monitoring*
The Quapaw Tribe of Oklahoma and USGS will be conducting monthly sampling of Spring River, Tar Creek, and Beaver Creek to determine the extent of possible contamination, through a cooperative agreement with EPA under the Clean Water Act Section 106. The Quapaw Tribe of Oklahoma retains ownership of almost 80 percent of the land that is underlain with mines. The Tribe has discovered 79 point-source discharges of chemicals listed on the Toxic Release Inventory. The Spring River flows through this land. The Water Quality Monitoring Program will sample at two stations along the Spring River. In addition, Tar Creek and Beaver Creek will be examined to determine the extent of possible impact. The Tribal Ecologist, along with support from the EPA, will conduct monthly sampling for total dissolved solids, nitrates, phosphorus, nutrients, bacteria, metals, and the Biological Oxygen Demand. In accordance with the Quapaw Tribe contract, the USGS will aid in collecting and analyzing samples on a quarterly (sampling for bacteria, nutrients, and metals) and a semi-annual basis (total organics, perchlorate, and MTBE) so that it can be determined whether or not the Spring River, Tar Creek, and Beaver Creek are meeting the standards for criteria pollutants as established by the OWRB. The Quapaw Water Quality Assurance Project Plan (QAPP) outlines specifically the work plan for this monitoring. Requests for a copy of the QAPP should be made to the Quapaw Tribe.

*Activity 3: DEQ & USGS Groundwater Investigation*
The groundwater in the Tar Creek area will be studied through a joint effort between the USGS and ODEQ (see Appendix D). This study will attempt to determine rates of movement of groundwater through the Picher Mining District by age dating the groundwater with chlorofluorocarbons (CFC's). The proposed project would provide State Officials with updated information about groundwater flow directions and rates of recharge in the Boone Chert of the Picher Mining District. These data will be useful in estimating areas of contribution to

contaminated streams draining the District and identifying the age of the water so that appropriate remediation activities can be developed.

*Activity 4: OWRB BUMP Monitoring*
Through its Beneficial Use Monitoring Program (BUMP) the OWRB monitors two locations on the Spring River and Neosho River previously sampled by the Oklahoma State Department of Health between 1979 and 1984 as part of the historical Ambient Trend Monitoring Program. It also assesses water quality in Grand Lake to determine trophic state and water quality trends, as well as document beneficial use support.

The OWRB will continue to monitor surface water in the Tar Creek area to the extent that legislative financial support continues. Specific permanent monitoring stations on the Neosho River at Conners Bridge west of Commerce and the Spring River at Devils Prominade (East of Quapaw) will continue to be monitored monthly . Grand Lake will be monitored every other year quarterly to document water quality trends, trophic status and beneficial use support. The OWRB also publishes an annual report documenting results of the BUMP.
Results of 1998 and 1999 BUMP sampling indicated that the overall water quality of the Neosho River at Conners Bridge and Spring River near Quapaw is relatively good. The following is a brief excerpt from the OWRB 1999 Draft BUMP Final Report to the Oklahoma Legislature outlining the results of water quality monitoring efforts at the two sites.

***Neosho River near Connor Bridge***

Station AT185010 is a permanent ambient trend monitoring station located on the Neosho River in Oklahoma. Situated in the central portion of Ottawa County, the site was established south southeast of the city of Miami off of State Highway 137 on County Road E0145 at Connor Bridge. The station is positioned near the terminal end of stream segment 121600040010 and is classified within the Grand Lake 8 digit HUC watershed (11070206). Water enters the stream system from several tributaries including Tar Creek and Hudson Creek, among others.

This station on the Neosho River has been active for all water quality variables since November of 1998. The following assessment of beneficial uses is based on the required 10 months of data collected from January through October of 1999. For purposes of reporting, this station is representative of the Neosho River from the confluence of an unnamed tributary above the city of Miami, Oklahoma (-94.9116, 36.8757) downstream to confluence of the Neosho River with Grand Lake (-94.7866, 36.7919). As per Appendix A, Table 1 of OAC 785:45, this water quality management segment is assigned the following designated beneficial uses: 1) Public and Private Water Supply (PPWS), 2) Warm Water Aquatic Community—Fish and Wildlife Propagation (WWAC), 3) Agriculture—Class I Irrigation (AG), and 4) Primary Body Contact—Recreation (PBCR).

The PPWS beneficial use support could not be determined due to an insufficient number of fecal coliform and metals samples. The WWAC beneficial use is not supported. Of the ten (10) turbidity samples (Figure 112), three (3) samples (or 30%) exceeded the numerical criteria of 50. Of the ten (10) pH samples (Figure 111), two (2) samples (or 20%) exceeded the screening level of 9.0 units. Dissolved oxygen (Figure 110) data collected during the same period met the criteria prescribed in the WWAC beneficial use. There is insufficient data to assess the WWAC beneficial use for metals. The AG beneficial use is supported for total dissolved solids (TDS), chlorides, and sulfates (Figure 113). Although the TDS sample standard is exceeded 6 (six) times and the TDS yearly mean standard is not met by the geometric mean, these numbers are still below the prescribed minimum TDS value of 750 mg/L. The PBCR beneficial use can not be determined due to an insufficient number of fecal coliform, *E. coli* and enterococci samples (Figure 114). This segment of the Neosho River is not nutrient-threatened. Only two (2) of the ten (10) total phosphorus concentrations (or 20%) and none of the ten (10) nitrate/nitrite concentrations were above the prescribed thresholds of 0.36 mg/L and 5.00 mg/L, respectively (Figure 115). Furthermore, the station is light-limited due to a mean turbidity of 48 NTU.

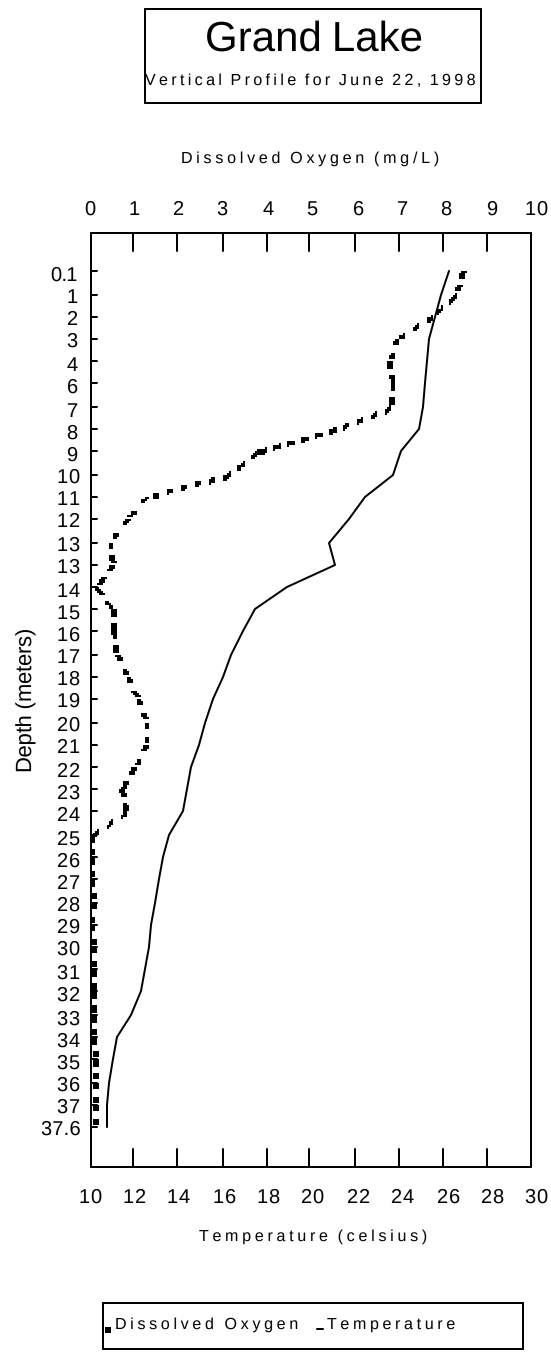
### ***Spring River near Quapaw***

Station AT188000 is a permanent ambient trend monitoring station located on Spring River in Oklahoma. Situated in the north central portion of Ottawa County, the site was established east-southeast of the city of Quapaw off of State Highway 137 on County Road E0050. The station is positioned near the midpoint of stream segment 121600070010 and is classified within the Spring River 8 digit HUC watershed (11070207). Water enters the stream system from Kansas and from several tributaries including Five Mile Creek, Devil's Hollow Creek, Warren Branch Creek, and Flint Branch Creek, among others.

This station on the Spring River has been active for all water quality variables since November of 1998. The following assessment of beneficial uses is based on the required 10 months of data collected from January through October of 1999. For purposes of reporting, this station is representative of the Spring River from the confluence of Bluff Creek (-94.7118, 36.9988) downstream to confluence of the Spring River with the Salt Fork of the Arkansas River (-94.7342, 36.8322). As per Appendix A, Table 1 of OAC 785:45, this water quality management segment is assigned the following designated beneficial uses: 1) Public and Private Water Supply (PPWS), 2) Cool Water Aquatic Community—Fish and Wildlife Propagation (CWAC), 3) Agriculture—Class I Irrigation (AG), and 4) Primary Body Contact—Recreation (PBCR).

The PPWS beneficial use support can not be determined due to an insufficient number of fecal coliform and metals samples. The CWAC beneficial use is not supported. Of the ten (10) turbidity samples (Figure 130), ten (10) samples (or 100%) exceeded the numerical criteria of 10. Dissolved oxygen (Figure 128) and pH (Figure 129) data collected during the same period met the criteria prescribed in the CWAC beneficial use. There is insufficient data to assess the CWAC beneficial use for metals. The AG beneficial use is supported for total dissolved solids (TDS), chlorides, and sulfates (Figure 131). Although the TDS sample standard is exceeded 5 (five) times and the TDS yearly mean standard is not met by the geometric mean, these numbers are still below the prescribed minimum TDS value of 750 mg/L. The PBCR beneficial use can not be determined due to an insufficient number of fecal coliform, *E. coli* and enterococci samples (Figure 132). This segment of the Spring River is not nutrient-threatened. None of the ten (10) total phosphorus concentrations and nitrate/nitrite concentrations were above the prescribed thresholds of 0.36 mg/L and 5.00 mg/L, respectively (Figure 133). Furthermore, the station is light-limited due to a mean turbidity of 28 NTU.

In addition, the OWRB sampled Grand Lake in 1998 for a suite of water quality parameters. A short synopsis of 1998 lake sampling efforts is presented below.




**GRAND LAKE**

Sampling was conducted on Grand Lake in June of 1998 for numerous water quality parameters, in order to assess lake trophic status. The lake had an average lake-wide turbidity value of 6 NTU, an average lake-wide chlorophyll-a value of 22.92 g/l, and an average secchi disk depth of approximately 91 centimeters. A trophic state index was calculated for the reservoir using Carlson's TSI and chlorophyll-a as the trophic state indicator parameter of primary interest. The lake had a calculated TSI of 61, which indicated the water body was hypereutrophic in nature, with some areas characterized by eutrophic conditions (Plate 45). The lake was manifesting high to excessively high primary productivity. The lake was sampled at 12 sites to represent the riverine, transitional, and lacustrine zones of the reservoir as well as the major arms or embayments of the water body. Water quality samples were collected at all sample sites at the lake surface and additional samples were collected approximately 0.5 meters from the lake bottom at sample site 1, the dam.

Vertical profiles for dissolved oxygen, pH, temperature, specific conductance, oxidation-reduction potential, and salinity were performed at all sample sites. Lake salinity values varied from 0.12 parts per thousand (ppt) to 0.17ppt which was well within the normal expected range of values for Oklahoma reservoirs. Readings for specific conductance ranged from a minimum of 0.244mS/cm up to a maximum value of 0.340mS/cm. In general, specific conductance values increased in a gradient from the lake dam to the twin bridges area, but all values recorded were within the normally expected range of values for Oklahoma lakes and in fact showed that the lake had low to moderate concentrations of electrical conducting compounds (i.e. salts) in the water column. Lake pH values showed the lake to be neutral to slightly alkaline in nature with values ranging from 6.77 up to 8.59. Moving down the water column, pH values decreased, which is a common occurrence. The lake was thermally stratified at a depth of 10 meters from the surface. Temperature readings dropped from 23.78°C at 10 meters to 22.5°C at the 11 meter depth. Dissolved oxygen values were recorded below 2.mg/l from the 10 meter depth to the lake bottom at 37.6 meters (Figure 68). Anoxic conditions were present in the hypolimnion and approximately 70% of the water column had dissolved oxygen concentrations less than 2.0mg/l. Low oxygen concentrations in the lake were a cause for concern and may in fact be a beneficial use impairment. Additional sampling should occur to document if an impairment is present. Oxidation-reduction potentials ranged from -191mV at sample site 10 to 189mV at site 1 near the dam. Reducing conditions were present in the hypolimnion of the lake and the possibility of nutrient release from bottom sediments was a concern.

In summary, Grand Lake was classified as hypereutrophic, indicative of excess primary productivity (Plate 45). The lake TSI did not met the minimum criteria for inclusion as a nutrient limited water in the OWQS. The reservoir was experiencing some water quality concerns at the time it was sampled due to hypereutrophy brought on by high nutrient concentrations. The lake was listed in Appendix D of OAC 785:46 (OWQS Implementation) as a threatened water body and the lake should be intensively monitored in the future to definitively document if beneficial use impairments are present. Sample results were in agreement with the Phase I Clean Lakes study findings. The ODEQ Rotating Lake Toxics sampling program has sampled the water body in 1980, 1983, 1986, and 1994. Sampling in 1980, 1983, and 1986 detected chlordane in fish flesh tissue at ODEQ warning and/or concern levels. When the lake was sampled in 1994, no toxic compounds were detected in fish flesh tissue.

The OWRB will investigate ways to evaluate other surface water quality needs such as 303(d)list refinement sampling, fish flesh analysis, and groundwater monitoring. Although dedicated, long-term funds have as yet not been appropriated for the BUMP, it is critical to Oklahoma's long term holistic water quality management program to continue a holistic, long-term water quality sampling program.

*Additional monitoring activities that should be pursued or considered are as follows:*
Spring River and Grand Lake should be monitored extensively over the next few years to evaluate trends or changes in water quality since studies in the 1980s and early 1990s were performed. Current monitoring programs by the OWRB, OCC and DEQ should be strengthened and coordinated to acquire quality data with a minimum of time and manpower expended.

Oklahoma State Environmental Agencies should work cooperatively with the Oklahoma Water Quality Monitoring Council and other partners to develop a long-term water quality monitoring program to work in conjunction with BUMP, TMDL monitoring, 303(d) list monitoring, and tribal activities, to maximize limited monitoring resources.

No current data exists which documents heavy metal concentrations in fish flesh tissue and the potential for this contamination to affect human health. We recommend that fish samples be collected and analyzed to determine if heavy metal concentrations in fish tissue constitute and cause for concern. We also recommend the fish collections occur in Spring River, the Neosho

River, and the upper end of Grand Lake near Twin-Bridges to document any potential adverse impacts to the lake or it's tributary biological communities. Also, it is vital that continued water quality sampling occur in the lake and watershed over a long-term time period to document any detrimental changes to water quality.

Additional data are required to identify, design, and implement potential treatment systems of the surface water in the Tar Creek Area. These data would consist of surface water monitoring to determine water quality and quantity at mine drainage discharge locations. It is estimated that three years may be required to obtain a representative set of water data. The data collection duration would allow for the possibility of an unseasonably dry or wet year (see Appendix A, Figure C).

*Activity 5: ITEC Beaver Creek RI/FS Project*
This project will focus almost exclusively on metals (primarily lead, zinc, and cadmium) in the water, sediment, and soil of the Beaver Creek watershed, particularly in the portions of Beaver Creek that flow through the Catholic 40 and the Quapaw Tribal Powwow Ground. The ITEC project is intended to determine, to the extent feasible, how much lead is present in the soil, sediment, and surface water of the creek, how that lead is impacting the health of tribal members using resources of the creek, and how contaminated media in the watershed may be remediated.

*Additional monitoring activities that should be pursued or considered are as follows:*
Spring River and Grand Lake should be monitored extensively over the next few years to evaluate trends or changes in water quality since the studies in the 1980s and early 1990s were performed. Current monitoring programs by the OWRB, OCC and DEQ should be strengthened and coordinated to acquire the quality data with a minimum of time and manpower expended.

Oklahoma State Environmental Agencies should work cooperatively with the Oklahoma Water Quality Monitoring Council and other partners to develop a long-term water quality monitoring program to work in conjunction with BUMP, TMDL monitoring, 303(d) list monitoring, and tribal activities, to maximize limited monitoring resources.

No data exists which documents heavy metal concentrations in fish flesh and the potential for this contamination to affect human health. We recommend that fish be collected and analyzed to determine if fish flesh are contaminated by heavy metals and document the potential impact to human health.

Additional data are required to identify, design, and implement potential treatment systems of the surface water in the Tar Creek Area. These data would consist of surface water monitoring to determine water quality and quantity at mine drainage discharge locations. It is estimated that three years may be required to obtain a representative set of water data. The data collection duration would allow for the possibility of an unseasonably dry or wet year (see Appendix A, Figure C).

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# APPENDIX A
# OWRB Sites and Drinking Water Standards

# Oklahoma Water Resources Board

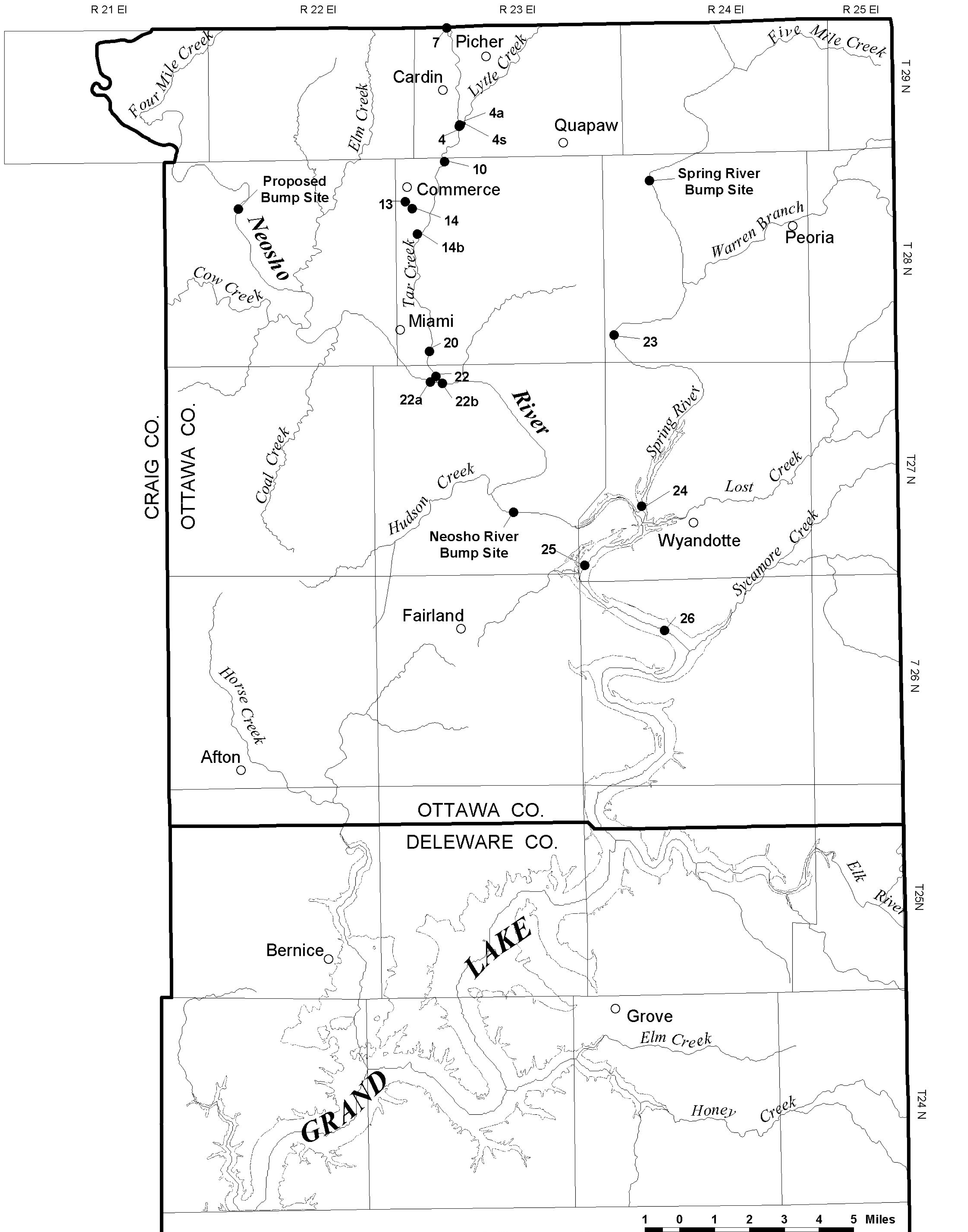



**Figure A**

# APPENDIX B
# Historical Monitoring Activity

### ***Surface Water Monitoring***

(For site locations see Appendix A, Figure A)

**Table 1 (1994 Five-Year Review)**

*Water Quality at Site 7*

| | Average Concentration (Total metals in ug/L, Sulfate in mg/L) | | |
|---|---|---|---|
| Constituent | 1980-82 | 1987-89 | %Change |
| Cadmium | 21.2 | 16.9 | -20 |
| Fluoride | 0.29 | 0.19 | -34 |
| Iron | 5663 | 799 | -86 |
| Lead | 58 | 107 | +84 |
| Sulfate | 626 | 341 | -46 |
| Zinc | 5870 | 3523 | -40 |
| | Average %Change | | -24 |
| Average pH | 7.0 SU | | |
| Average DO | 9.0 mg/L | | |
| Average Conductivity | 825 umhos/cm | | |

**Table 2 (1994 Five-Year Review)**

*Water Quality at Site 4a*

| | Average Concentration (Total metals in ug/L, Sulfate in mg/L) | | |
|---|---|---|---|
| Constituent | 1980-82 | 1987-89 | %Change |
| Cadmium | 23 | 27 | +17 |
| Fluoride | 0.9 | 0.4 | -56 |
| Iron | 11,433 | 1011 | -91 |
| Lead | 23 | 38 | +65 |
| Sulfate | 679 | 522 | -23 |
| Zinc | 26,270 | 7620 | -71 |
| | Average %Change | | -27 |
| Average pH | 6.6 SU | | |
| Average DO | 8.3 mg/L | | |
| Average Conductivity | 1350 umhos/cm | | |

**Table 3 (1994 Five-Year Review)**

*Water Quality at Site 4b*

| | Average Concentration (Total metals in ug/L, Sulfate in mg/L) | | |
|---|---|---|---|
| Constituent | 1980-82 | 1987-89 | %Change |
| Cadmium | 48 | 17 | -65 |
| Fluoride | 1.6 | 1.7 | +6 |
| Iron | NA | 73,112 | NA |
| Lead | 31 | 37 | +19 |
| Sulfate | 1,105 | 1,281 | +16 |
| Zinc | 26,371 | 31,259 | +19 |
| | Average %Change | | -1 |
| Average pH | 5.9 SU | | |
| Average DO | 6.3 mg/L | | |
| Average Conductivity | 2022 umhos/cm | | |

**Table 4 (1994 Five-Year Review)**
*Water Quality at Site 10*

| | Average Concentration (Total metals in ug/L, Sulfate in mg/L) | | |
|---|---|---|---|
| Constituent | 1980-82 | 1987-89 | %Change |
| Cadmium | 32 | 16 | -50 |
| Fluoride | 2.9 | 1.6 | -45 |
| Iron | 27,139 | 45,882 | +69 |
| Lead | 92 | 37 | -60 |
| Sulfate | 954 | 1,274 | +34 |
| Zinc | 37,246 | 28,823 | -23 |
| | | Average %Change | -13 |
| Average pH | 5.7 SU | | |
| Average DO | 6.6 mg/L | | |
| Average Conductivity | 2087 umhos/cm | | |

**Table 5 (1994 Five-Year Review)**
*Water Quality at Site 20*

| | Average Concentration (Total metals in ug/L, Sulfate in mg/L) | | |
|---|---|---|---|
| Constituent | 1980-82 | 1987-89 | %Change |
| Cadmium | 19 | 13 | -32 |
| Fluoride | 2.2 | 1.2 | -45 |
| Iron | 8,853 | 20,034 | +126 |
| Lead | 33 | 37 | +12 |
| Sulfate | 619 | 1,186 | +92 |
| Zinc | 21,333 | 21,408 | 0 |
| | | Average %Change | +18 |
| Average pH | 5.2 SU | | |
| Average DO | 6.1 mg/L | | |
| Average Conductivity | 1606 umhos/cm | | |

**Table 6 (1994 Five-Year Review)**
*Water Quality at Site 22*

| | Average Concentration (Total metals in ug/L, Sulfate in mg/L) | | |
|---|---|---|---|
| Constituent | 1980-82 | 1987-89 | %Change |
| Cadmium | 5 | 9 | +80 |
| Fluoride | 0.6 | 1.0 | +67 |
| Iron | 1,260 | 10,928 | +767 |
| Lead | 20 | 38 | +90 |
| Sulfate | 152 | 969 | +538 |
| Zinc | 6,083 | 15,149 | +149 |
| | | Average %Change | +282 |
| Average pH | 6.6 SU | | |
| Average DO | 9.8 mg/L | | |
| Average Conductivity | 1602 umhos/cm | | |

**Table 7** (OWRB 1983)
*Statistical Summary of Stream Water Quality Data*

| *Site Number* | *Number of Samples* | *Mean* | *Std. Dev* | *Minimum* | *Maximum* |
|---|---|---|---|---|---|
| | | | *Specific Conductance* | | |
| 7 | 9 | 1249 | 485 | 590 | 1676 |
| 4a | 23 | 1484 | 404 | 896 | 2130 |
| 4 | 25 | 2136 | 803 | 1000 | 3880 |
| 10 | 26 | 1981 | 764 | 310 | 3140 |
| 14b | 8 | 2402 | 455 | 1960 | 3380 |
| 20 | 25 | 1554 | 754 | 190 | 3140 |
| 22 | 6 | 829 | 394 | 511 | 1424 |
| 22a | 7 | 380 | 124 | 253 | 565 |
| 22b | 9 | 396 | 114 | 255 | 556 |
| 23 | 3 | 257 | 73 | 215 | 342 |
| 24 | 3 | 244 | 58 | 211 | 311 |
| | | | *pH* | | |
| 7 | 9 | 6.5 | 0.50 | 5.8 | 7.4 |
| 4a | 23 | 6.2 | 0.70 | 5.2 | 8.3 |
| 4 | 25 | 5.7 | 0.81 | 3.9 | 7.7 |
| 10 | 26 | 5.7 | 1.30 | 3.3 | 7.7 |
| 14b | 8 | 4.1 | 0.53 | 3.6 | 4.9 |
| 20 | 26 | 5.4 | 1.80 | 2.9 | 8.5 |
| 22 | 6 | 6.5 | 0.40 | 6.0 | 7.2 |
| 22a | 7 | 7.1 | 0.40 | 6.7 | 7.7 |
| 22b | 9 | 7.2 | 0.50 | 6.7 | 7.9 |
| 23 | 3 | 6.8 | 0.50 | 6.5 | 7.4 |
| 24 | 3 | 6.7 | 0.40 | 6.5 | 7.2 |
| | | | *DO (mg/L)* | | |
| 7 | 8 | 4.1 | 2.5 | 0.8 | 7.5 |
| 4a | 20 | 4.7 | 2.5 | 1.3 | 9.2 |
| 4 | 24 | 3.9 | 2.4 | 1.1 | 8.5 |
| 10 | 25 | 4.9 | 3.1 | 0.7 | 12.0 |
| 14b | 8 | 2.3 | 2.5 | 0.7 | 6.3 |
| 20 | 24 | 6.0 | 3.5 | 0.9 | 13.0 |
| 22 | 5 | 4.7 | 1.9 | 1.8 | 6.4 |
| 22a | 6 | 4.1 | 1.3 | 1.9 | 5.3 |
| 22b | 8 | 5.7 | 2.0 | 1.9 | 8.7 |
| 23 | 3 | 5.4 | 1.5 | 4.5 | 7.1 |
| 24 | 3 | 4.7 | 0.6 | 4.4 | 5.5 |
| | | | *Iron (ug/L)* | | |
| 7 | 7 | 7871 | 19,461 | 150 | 52,000 |
| 4a | 13 | 12,020 | 26,062 | 510 | 96,000 |
| 4 | 16 | 53,751 | 82,637 | 430 | 290,000 |
| 10 | 19 | 27,137 | 42,500 | 280 | 162,000 |
| 14b | 19 | 53,450 | 60,648 | 2600 | 129,000 |
| 20 | 20 | 8853 | 14,972 | 550 | 52,000 |
| 22a | 3 | 1703 | 1002 | 1100 | 2860 |
| 22b | 6 | 1083 | 780 | 280 | 2590 |
| 23 | 1 | 1430 | - | 1430 | 1430 |
| 24 | 1 | 2100 | - | 2100 | 2100 |

| *Site Number* | *Number of Samples* | *Mean* | *Std. Dev* | *Minimum* | *Maximum* |
|---|---|---|---|---|---|
| | | | *Zinc (ug/L)* | | |
| 7 | 7 | 6493 | 4219 | 2100 | 13,800 |
| 4a | 13 | 27,398 | 24,831 | 3980 | 80,000 |
| 4 | 16 | 38,644 | 37,473 | 8700 | 141,000 |
| 10 | 19 | 37,247 | 37,473 | 3390 | 151,000 |
| 14b | 4 | 87,250 | 45,573 | 28,000 | 137,000 |
| 20 | 20 | 21,333 | 27,879 | 281 | 104,000 |
| 22 | 4 | 4582 | 6489 | 78 | 14,200 |
| 22a | 3 | 485 | 614 | 66 | 1190 |
| 22b | 6 | 325 | 293 | 58 | 720 |
| 23 | 1 | 161 | - | 161 | 161 |
| 24 | 1 | 238 | - | 238 | 238 |
| | | | *Cadmium (ug/L)* | | |
| 7 | 7 | 17.6 | 4.5 | 11 | 23 |
| 4a | 12 | 24.0 | 16.0 | 8 | 59 |
| 4 | 16 | 56.0 | 65.0 | 12 | 260 |
| 10 | 19 | 32.0 | 23.0 | 5 | 82 |
| 14b | 4 | 43.0 | 21.0 | 23 | 69 |
| 20 | 20 | 18.6 | 19.0 | <2 | 63 |
| 22 | 4 | 4.0 | 4.5 | <2 | 11 |
| 22a | 3 | 2.7 | 0.6 | <2 | 3 |
| 22b | 6 | 2.1 | 0.4 | 2 | 3 |
| 23 | 1 | <2.0 | - | <2 | <2 |
| 24 | 1 | <2 | - | <2 | <2 |
| | | | *Lead (ug/L)* | | |
| 7 | 5 | 71.8 | 100.0 | <20 | 247 |
| 4a | 11 | 23.0 | 8.8 | <20 | 49 |
| 4 | 13 | 171.0 | 526.0 | <20 | 1920 |
| 10 | 18 | 92.0 | 251.0 | <20 | 1090 |
| 14b | 4 | 26.7 | 13.5 | <20 | 47 |
| 20 | 19 | 33.0 | 41.0 | <20 | 196 |
| 22 | 3 | <20 | 0.0 | <20 | <20 |
| 22a | 2 | <20 | 0.0 | <20 | <20 |
| 22b | 6 | <20 | 0.0 | <20 | <20 |
| 23 | 1 | <20 | - | <20 | <20 |
| 24 | 1 | 27.0 | - | 27 | 27 |
| | | | *Chromium (ug/L)* | | |
| 7 | 3 | <10 | 0.0 | <10 | <10 |
| 4a | 5 | <10 | 0.0 | <10 | <10 |
| 4 | 9 | 11.6 | 3.2 | <10 | 19 |
| 10 | 13 | 13.5 | 7.1 | <10 | 30 |
| 14b | 3 | <10 | 0.0 | <10 | <10 |
| 20 | 14 | 18.0 | 21.0 | <10 | 88 |
| 22 | 3 | <10 | 0.0 | <10 | <10 |
| 22a | 2 | <10 | 0.0 | <10 | <10 |
| 22b | 5 | <10 | 0.0 | <10 | <10 |
| 23 | 1 | <10 | - | <10 | <10 |
| 24 | 1 | <10 | - | <10 | <10 |

| *Site Number* | *Number of Samples* | *Mean* | *Std. Dev* | *Minimum* | *Maximum* |
|---|---|---|---|---|---|
| | | | *Fluoride (mg/L)* | | |
| 7 | 8 | 0.29 | 0.10 | 0.19 | 0.43 |
| 4a | 14 | 0.90 | 0.60 | 0.40 | 2.60 |
| 4 | 14 | 2.90 | 2.90 | 0.38 | 11.80 |
| 10 | 14 | 2.90 | 1.60 | 0.40 | 5.20 |
| 14b | 3 | 3.15 | 1.10 | 2.21 | 4.34 |
| 20 | 14 | 2.15 | 1.40 | 0.23 | 5.70 |
| 22 | 4 | 0.60 | 0.31 | 0.38 | 1.06 |
| 22a | 5 | 0.30 | 0.04 | 0.23 | 0.31 |
| 22b | 4 | 0.26 | 0.03 | 0.23 | 0.29 |
| 23 | 1 | <0.10 | - | <0.10 | <0.10 |
| 24 | 1 | <0.10 | - | <0.10 | <0.10 |

**Table 8** (OWRB 1983)
*Statistical Summary of Water Quality Data for Site 7 (Oklahoma-Kansas State Line)*

| *Parameter* | *# of Samples* | *Mean* | *Std. Dev.* | *Minimum* | *Maximum* |
|---|---|---|---|---|---|
| Alkalinity, Total (mg/L) | 3 | 112.0 | 53.5 | 73 | 173.0 |
| Aluminum, Total (ug/L) | 3 | 3* | 0 | 3* | 3* |
| Arsenic, Total (ug/L) | 3 | 10* | 0 | 10* | 10* |
| Cadmium, Total(ug/L) | 7 | 17.6 | 4.5 | 11.0 | 23.0 |
| Chromium, Total(ug/L) | 3 | 10* | 0 | 10* | 10* |
| Copper, Total(ug/L) | 3 | 10.6 | 9.0 | 4.0* | 20.0 |
| Dissolved Oxygen (mg/L) | 8 | 4.1 | 2.5 | 0.8 | 7.5 |
| Fluoride, Total (mg/L) | 8 | 0.3 | 0.1 | 0.2 | 0.4 |
| Iron, Total(ug/L) | 7 | 7871 | 19,461 | 150 | 52,000 |
| Lead, Total(ug/L) | 5 | 72 | 100 | 20* | 247 |
| Manganese, Total(ug/L) | 5 | 180 | 115 | 60 | 370 |
| Mercury, total(ug/L) | 3 | 0.5* | 0.0 | 0.5* | 0.5* |
| Nickel, Total(ug/L) | 3 | 56 | 25 | 28 | 78 |
| pH | 9 | 6.5 | 0.5 | 5.8 | 7.4 |
| Solids, Total (mg/L) | 2 | 634 | 198 | 494 | 774 |
| Diss. Solids, Total (mg/L) | 8 | 1011 | 574 | 437 | 1844 |
| Specific Conductance | 9 | 1249 | 485 | 590 | 1676 |
| Sulfate (mg/L) | 8 | 627 | 406 | 189 | 1296 |
| Zinc, Total (ug/L) | 7 | 5870 | 4219 | 2100 | 13,800 |

*Concentrations below detection limit

## *Fish Filet Data*

**Table 9** Fish Filet Data (TCTFHES, 1983)

| Site (Dates) | Number of Samples | Lead Mean | mg/kg Min | Max | Cd Mean | mg/kg Min | Max | Zinc Mean | mg/kg Min | Max |
|---|---|---|---|---|---|---|---|---|---|---|
| Tar Creek | | | | | | | | | | |
| 22 (mouth) | 6 | 0.5 | *1 | *1.0 | 0.1 | *0.1 | *0.1 | 15.3 | 1.0 | 58.5 |
| Neosho River | | | | | | | | | | |
| (22A) | 6 | 0.5 | *1 | *1.0 | 0.1 | 0.1 | *0.1 | 7.4 | 4.4 | 10.5 |
| (22B) | 6 | 0.5 | *1 | *1.0 | 0.1 | *0.1 | *0.1 | 5.5 | 3.9 | 8.9 |
| Spring River | | | | | | | | | | |
| (23) | 7 | 0.5 | *1 | *1.0 | 0.1 | *0.1 | 0.2 | 7.6 | 2.2 | 13.9 |
| (24) | 8 | 0.5 | *1 | *1.0 | 0.1 | *0.1 | *0.1 | 4.7 | 1.1 | 7.7 |
| Grand Lake | | | | | | | | | | |
| (25) | 7 | 0.5 | *1 | *1.0 | 0.1 | *0.1 | *0.1 | 9.6 | 4.9 | 22.5 |
| (26) | 6 | 0.5 | *1 | *1.0 | *0.1 | *0.1 | *0.1 | 7.5 | 4.6 | 13.4 |

*Less than detection limit.
Tar Creek Task Force Health Effects Subcommittee (TCTFHES), 1983, “An Environmental Health Evaluation of the Tar Creek Area”, March 1983, 36pp

**Table 10** *(Final Remedial Investigation for Cherokee County, Kansas)*
Fish Wholebody Analytical Results

| Location | Sample I.D. | Species | Metals (mg/kg-wet weight) Cadmium | Lead | Zinc |
|---|---|---|---|---|---|
| Tar Creek | TC-3(1) | Warmouth/Redear | 0.31 | 14 | 203 |
| Treece Pond 0.5 mile east of Treece | TP-5(1) | Green Sunfish | 0.160 | 4.00 | 219.0 |
| Treece Pond Near Tar Creek 1.0 mile upstream from Oklahoma | TP-6(1) | Green Sunfish | 0.075 | 1.20 | 60.3 |
| | TP-6(2) | Green Sunfish | 0.954 | 4.40 | 106.0 |
| | TP-6(3) | Green Sunfish | 0.220 | 3.60 | 70.3 |
| Treece Pond (Muncie Pond) | TP-7(6) | Bluegill | 0.077 | 4.80 | 52.9 |
| | TP-7(7) | Bluegill | 0.754 | 19.60 | 199.0 |
| | TP-7(8) | Bluegill | 0.240 | 9.20 | 109.0 |

Reference Concentrations:

| | Cadmium | Lead | Zinc |
|---|---|---|---|
| Neosho River at Chetopa (bottomfeeders) | <0.05-0.30 | 0.24-1.40 | 12.00-67.5 |
| Neosho River at Chetopa (mixed species) | 0.06 | 0.42 | --- |
| Spring River at Baxter Springs (bottomfeeders) | 0.1-0.71 | <0.50-2.06 | 53.3-99.00 |
| Spring River at Baxter Springs (mixed species) | 0.17 | 2.34 | 79.2 |

**Table 11** *(Final Remedial Investigation for Cherokee County, Kansas)*
*Fish Filet Analytical Results*

| Location | Sample I.D. | Species | Metals (mg/kg-wet weight) Cadmium | Lead | Zinc |
|---|---|---|---|---|---|
| Treece Pond Near Tar Creek 1.0 mile upstream from Oklahoma | TP-6(4) | Green Sunfish | 0.008 | 0.05 | 8.65 |
| Treece Pond (Muncie Pond) | TP-7(1) | Largemouth Bass | <0.002 | 0.03 | 4.57 |
| | TP-7(2) | Largemouth Bass | 0.003 | <0.02 | 4.38 |
| | TP-7(3) | Largemouth Bass | 0.004 | 0.03 | 6.26 |
| | TP-7(4) | Black Bullhead | 0.012 | 0.06 | 7.24 |
| | TP-7(5) | Black Bullhead | 0.005 | 0.05 | 7.15 |
| Baxter Springs | WC-P(1) | Largemouth Bass | 0.004 | <0.02 | 4.51 |
| | SB-2(5) | Green Sunfish | 0.250 | 0.03 | 7.19 |
| | BP-3(7) | Green Sunfish | 0.054 | <0.02 | 2.18 |
| | BP-4(1) | Black Bullhead | 0.022 | 0.03 | 3.45 |

**Table 12** *(Final Remedial Investigation for Jasper County, Missouri)*
*Wholebody Fish Tissue Results-Streams*

| Location | Wet Weight (µg/g) Cadmium | Lead | Zinc |
|---|---|---|---|
| Spring River (Pelagic) | | | |
| SR-1 (control); n=3 | 0.016 (0.12-0.21) | <0.050 (<0.050-<0.050) | 19.77 (17.96-22.36) |
| SR-2; n=3 | 0.009 (0.007-0.012) | <0.050 (<0.050-<0.050) | 21.73 (17.48-28.69) |
| Mean of Means Downstream Locations; (n=8) | 0.184 | 0.759 | 45.83 |
| Spring River (Bottom-Dwelling) | | | |
| SR-1 (control); n=3 | 0.041 (0.022-0.051) | 0.092 (0.076-0.105) | 32.36 (18.95-53.80) |
| SR-2; n=3 | 0.028 (0.017-0.044) | 0.09 (<0.050-0.140) | 24.03 (22.65-26.28) |
| Mean of Means Downstream Locations; n=6 | 0.224 | 1.421 | 57.43 |

**Table 13** *(Final Remedial Investigation for Jasper County, Missouri)*
*Component Fish Results-Streams*

| | Location | Filet | Wet Weight (µg/g) Gut | Residual |
|---|---|---|---|---|
| Cadmium | | | | |
| | SR-1 (Pelagic) | 0.002 (4%) | 0.051 (95%) | <0.001 (1%) |
| | 2SR-1 (Bottom-Dwelling) | 0.002 (<1%) | 0.279 (92%) | 0.023 (8%) |
| Lead | | | | |
| | SR-1 (Pelagic) | 0.089 (64%) | <0.050 (18%) | <0.050 (18%) |
| | SR-1 (Bottom-Dwelling) | <0.050 (2%) | 1.281 (96%) | <0.050 (2%) |
| Zinc | | | | |
| | SR-1 (Pelagic) | 6.67 (15%) | 20.25 (47%) | 16.56 (38%) |
| | SR-1 (Bottom-Dwelling) | 7.62 (15%) | 23.70 (45%) | 21.18 (40%) |

## *Acid Mine Discharges*

**Table 14 (1994 Five-Year Review)**
*Water Quality at Site 4S – weir in springs south of Lytle Creek*

| | Average Concentration (Total metals in ug/L, Sulfate in mg/L) | | |
|---|---|---|---|
| Constituent | 1980-82 | 1987-89 | %Change |
| Cadmium | 130 | 19 | -85 |
| Fluoride | 13 | 4 | -69 |
| Iron | 352,048 | 170,033 | -52 |
| Lead | 68 | 65 | -4 |
| Sulfate | 3,096 | 2,184 | -29 |
| Zinc | 231,814 | 62,161 | -73 |
| | | Average %Change | -52 |

**Table 15 (1994 Five-Year Review)**
*Water Quality at Site 4L – weir set in the old Lytle Creek channel. No pre-construction data available*

| | Average Concentration (Total metals in ug/L, Sulfate in mg/L) | | |
|---|---|---|---|
| Constituent | 1980-82 | 1987-89 | %Change |
| Cadmium | | 12 | |
| Fluoride | | 2.3 | |
| Iron | | 64,840 | |
| Lead | | 60 | |
| Sulfate | | 2,145 | |
| Zinc | | 49,625 | |

**Table 16 (1994 Five-Year Review)**
*Water Quality at Site 13 – weir designed to measure flow from a collapsed mine shaft*

| | Average Concentration (Total metals in ug/L, Sulfate in mg/L) | | |
|---|---|---|---|
| Constituent | 1980-82 | 1987-89 | %Change |
| Cadmium | 239 | 29 | -88 |
| Fluoride | 6 | 1 | -83 |
| Iron | 168,700 | 100,985 | -40 |
| Lead | 97 | 60 | -41 |
| Sulfate | 1,900 | 1,843 | -3 |
| Zinc | 86,250 | 17,645 | -80 |
| | | Average %Change | -56 |

**Table 17 (1994 Five-Year Review)**
*Water Quality at Site 14 – Spring which is the southernmost known acid mine discharge*

| | Average Concentration (Total metals in ug/L, Sulfate in mg/L) | | |
|---|---|---|---|
| Constituent | 1980-82 | 1987-89 | %Change |
| Cadmium | 13 | 13 | 0 |
| Fluoride | 5 | 2 | -60 |
| Iron | 500,827 | 288,300 | -42 |
| Lead | 33 | 57 | +73 |
| Sulfate | 2,892 | 2,438 | -12 |
| Zinc | 125,214 | 19,072 | -85 |
| | | Average %Change | -21 |

**Table 18** (OWRB 1983)
*Statistical Summary of Water Quality Data for Mine Discharges*

**Site 4S**

| *Parameter* | *No. of Samples* | *Mean* | *Std. Dev.* | *Minimum* | *Maximum* |
|---|---|---|---|---|---|
| Specific Conductance | 38 | 4236 | 757 | 2510 | 5500 |
| PH | 38 | 4.9 | 0.3 | 4.4 | 5.5 |
| DO, Total (mg/L) | 36 | 0.53 | 0.33 | 0.00 | 1.40 |
| Iron, Total (ug/L) | 18 | 355,833 | 69,497 | 253,000 | 480,000 |
| Zinc, Total (ug/L) | 18 | 228,061 | 102,056 | 14,000 | 342,000 |
| Cadmium, Total (ug/L) | 18 | 135 | 75.0 | 27 | 310 |
| Lead, Total (ug/L) | 16 | 60.0 | 35.6 | <20 | 141 |
| Chromium, Total (ug/L) | 14 | 8.2 | 5.6 | <10 | 22 |
| Fluoride, Total (mg/L) | 19 | 13.70 | 6.90 | 1.55 | 21.60 |

**Site 13**

| Parameter | No. of Samples | Mean | Std. Dev. | Minimum | Maximum |
|---|---|---|---|---|---|
| Specific Conductance | 11 | 3659 | 441 | 3150 | 4530 |
| pH | 11 | 2.5 | 0.4 | 1.9 | 3.3 |
| DO, Total (mg/L) | 9 | 3.50 | 2.40 | 1.40 | 8.90 |
| Iron, Total (ug/L) | 4 | 109,750 | 17,347 | 92,000 | 133,000 |
| Zinc, Total (ug/L) | 4 | 88,750 | 30,609 | 56,000 | 130,000 |
| Cadmium, Total (ug/L) | 4 | 362 | 74.0 | 260 | 430 |
| Lead, Total (ug/L) | 3 | 199.0 | 81.0 | 121 | 282 |
| Chromium, Total (ug/L) | 1 | 14.0 | - | 14 | 14 |
| Fluoride, Total (mg/L) | 8 | 6.60 | 0.50 | 6.00 | 7.39 |

**Site 14**

| Parameter | No. of Samples | Mean | Std. Dev. | Minimum | Maximum |
|---|---|---|---|---|---|
| Specific Conductance | 34 | 4278 | 1149 | 2510 | 9300 |
| PH | 34 | 5.6 | 0.3 | 5.0 | 6.7 |
| DO, Total (mg/L) | 33 | 0.60 | 0.32 | 0.00 | 1.40 |
| Iron, Total (ug/L) | 21 | 530,000 | 125,100 | 310,000 | 900,000 |
| Zinc, Total (ug/L) | 21 | 145,105 | 104,698 | 1200 | 560,000 |
| Cadmium, Total (ug/L) | 21 | 14 | 6.8 | 5 | 27 |
| Lead, Total (ug/L) | 20 | 20.2 | 31.5 | <20 | 120 |
| Chromium, Total (ug/L) | 16 | 10.2 | 8.8 | <10 | 32 |
| Fluoride, Total (mg/L) | 19 | 4.80 | 2.08 | 2.63 | 12.12 |

## *Sediment Sampling*

**Table 19** (1994 Five-Year Review)

**Sediment Concentrations (mg/kg)**

| | *1980-1982* | | | *1987-1989* | | |
|---|---|---|---|---|---|---|
| Site | Iron | Lead | Zinc | Iron | Lead | Zinc |
| 7 | 3267 | 101 | 2267 | 3155 | 526 | 8420 |
| 4a | 7878 | 289 | 5083 | 4673 | 562 | 5075 |
| 4b | 123950 | 967 | 13850 | 20629 | 388 | 31258 |
| 10 | 30000 | 320 | 5100 | 86557 | 888 | 19907 |
| 20 | 118333 | 246 | 6950 | 65534 | 245 | 4457 |
| 22 | 19000 | 53 | 5675 | 77935 | 290 | 6117 |

## *Tailings Piles in the Picher Field*

**Table 20**
Summary Water Quality for Mine Tailings (Site St) (OWRB, 1983)

| **Parameters** | **11/29/82** | **11/30/82** | **12/2/82** |
|---|---|---|---|
| PH | 5.3 | 5.1 | 5.0 |
| DO (mg/L) | 0.2 | 0.0 | 0.2 |
| SC, umhos/cm | 2,470 | 2,430 | 2,440 |
| Cadmium, ug/L | 46 | 20 | 26 |
| Iron, ug/L | 9,400 | 6,500 | 520,000 |
| Lead, ug/L | 305 | 74 | 106 |
| Zinc, ug/l | 29,000 | 16,600 | 17,000 |

Oklahoma Water Resources Board, 1983, Tar Creek Field Investigation Task 1.2, "Water Quality Characteristics of Seepage and Runoff at Two Tailings Piles in the Picher Field of Ottawa County, Oklahoma", March, 1983, p. 13.

**Table 21**
Summary Water Quality for Mine Tailings (Site 4t) (OWRB, 1983)

| **Parameters** | **11/29/82** | **11/30/82** | **12/01/82** | **12/02/82** | **12/3/82** |
|---|---|---|---|---|---|
| PH | 5.6 | 5.4 | 4.5 | 5.1 | 5.0 |
| DO (mg/L) | 1.1 | 0.5 | 0.0 | 0.3 | 0.3 |
| SC, umhos/cm | 2,620 | 2,630 | 2,650 | 2,330 | 2,520 |
| Cadmium, ug/L | 270 | 220 | 230 | 200 | 210 |
| Iron, ug/L | 180 | <100 | <100 | 120 | <100 |
| Lead, ug/L | 33 | <20 | <20 | 40 | <20 |
| Zinc, ug/L | 34,900 | 29,400 | 32,500 | 29,600 | 30,600 |

Oklahoma Water Resources Board, 1983, Tar Creek Field Investigation Task 1.2, "Water Quality Characteristics of Seepage and Runoff at Two Tailings Piles in the Picher Field of Ottawa County, Oklahoma", March, 1983, p. 12.

**Table 22**
**Tailings Piles** Table Showing Average Metals Loading Rates (OWRB, 1983)

| Constituent | Average Concentration, ug/L | Loading Rate Lbs/day (tons/year) |
|---|---|---|
| Cadmium | 153 | 0.153 (.027) |
| Chromium | 10.5 | 0.01 (.002) |
| Iron | 4,050 | 4.05 (.739) |
| Lead | 39 | 0.04 (.007) |
| Zinc | 27,450 | 27.50 (5.019) |

- Total Flow: 0.19 cfs (0.12 mgd)
- Total Chat Volume: 48.21 x $10^6$ $yd^3$

Oklahoma Water Resources Board, 1983, Tar Creek Field Investigation Task 1.2, "Water Quality Characteristics of Seepage and Runoff at Two Tailings Piles in the Picher Field of Ottawa County, Oklahoma", March, 1983, p. 8.

## *Ground Water Monitoring*

## *Boone Water Quality*

**Table 23**
*Statistical Summary of Selected Water Quality Data for Boone Boreholes sampled on 2/27/81 (OWRB,1983 )*

| *Parameter* | *# of Samples* | *Maximum* | *Minimum.* | *Mean* |
|---|---|---|---|---|
| Alkalinity, (mg/L $CaCO_3$) | 16 | 1,089 | 29 | 298 |
| Hardness (mg/L $CaCO_3$) | 6 | 3,103 | 419 | 1,424 |
| pH | 16 | 8.2 | 7.4 | 7.92 |
| Calcium, mg/L | 15 | 395 | 30 | 184 |
| Magnesium, mg/L | 16 | 780 | 10 | 207 |
| Spec Cond, (umhos/cm) | 16 | 5,000 | 525 | 2,423 |
| Arsenic, Total (ug/L) | 7 | 38 | 13 | 22 |
| Cadmium, Total (ug/L) | 15 | 133 | 4 | 25.9 |
| Iron, Total (ug/L) | 16 | 300,000 | 3,000 | 59,813 |
| Lead, Total (ug/L) | 7 | 124 | 33 | 63 |
| Manganese, Total (ug/L) | 16 | 9,800 | 150 | 3,318 |
| Sulfate (mg/L) | 14 | 3,395 | 184 | 1,360 |
| Zinc, Total (ug/L) | 16 | 252,000 | 40 | 19,911 |

Oklahoma Water Resources Board, 1983, Tar Creek Field Investigation Task 1.4, "Groundwater Investigation in the Picher Field, Ottawa County, Oklahoma, 3/83.

**Table 24** Concentrations (mg/L) of Chemical Constituents in Water Samples Collected in July, 1991 From OWRB Network Wells (Boone aquifer), (OWRB 2000)

| Site ID | Hardness | Alkalinity | TDS | Calcium | Magnesium | Sodium | Chloride | Floride | Nitrate as N | Sulfate | Barium | Iron | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **22-1** | 187 | 180 | 204 | 58 | 2 | <10 | <10 | <0.1 | 1.1 | 32 | 0.044 | 0.056 | 0.023 |
| **22-2** | 221 | 194 | 236 | 67 | 1 | <10 | <10 | <0.1 | 1.8 | 49 | 0.067 | 0.113 | <0.005 |
| **22-3** | 183 | 136 | 161 | 40 | 7 | <10 | <10 | <0.1 | <0.5 | <20 | 0.048 | 0.069 | <0.005 |
| **22-4** | 218 | 204 | 243 | 14 | 3 | 10 | 10 | 0.21 | 0.5 | <20 | 0.106 | <0.01 | 0.056 |
| **22-5** | 172 | 174 | 191 | 60 | <1 | <10 | <10 | 0.12 | <0.5 | <20 | 0.053 | 0.014 | <0.005 |
| **22-6** | 117 | 101 | 124 | 38 | <1 | <10 | <10 | <0.1 | 1 | <20 | 0.031 | 0.062 | <0.005 |
| **22-7** | 81 | 59 | 77 | 21 | <1 | <10 | <10 | <0.1 | 0.5 | <20 | <0.01 | 0.178 | <0.005 |
| **22-8** | 236 | 214 | 255 | 76 | 1 | <10 | <10 | <0.1 | 2.9 | 36 | 0.069 | 0.023 | <0.005 |
| **22-9** | 236 | 221 | 251 | 72 | 2 | <10 | 12 | 0.21 | <0.5 | 31 | 0.042 | 0.011 | <0.005 |
| **22-10** | 79 | 59 | 81 | 21 | <1 | <10 | <10 | <0.1 | 0.5 | <20 | 0.031 | 0.081 | <0.005 |
| **22-11** | 221 | 191 | 225 | 63 | 1 | <10 | <10 | 0.11 | <0.5 | <20 | 0.068 | 0.031 | 0.016 |
| **22-12** | 128 | 111 | 144 | 34 | <1 | <10 | <10 | <0.1 | 3 | 33 | 0.046 | 0.019 | <0.005 |

Osborn, N.I., 2000, “Boone Groundwater Basin Minor Basin Hydrogeologic Investigation Report, OWRB Technical Report (in Press)

**Table 25** Historical Water Quality data for Selected Boone Wells (OWRB, 1983)

| Site (Dates) | Location | SC, umhos/cm | PH | Ca mg/L | Mg Mg/L | Hard Mg/L | ***HCO3*** mg/L | SO4 mg/L | TDS mg/L | Fe ug/L |
|---|---|---|---|---|---|---|---|---|---|---|
| Well # 1 (4/29/48) | SWSWSW 4-T25N-R24E | 460 | - | - | - | 89 | 176 | 5 | 61 | - |
| Well #2 (10/1/60) | 19-T27N-R24E | 577 | 7.4 | 96 | 8.9 | 276 | 304 | - | 15 | - |
| Well #3 (6/6/56) | SE/4 31-T27N-R25E | 241 | 7.6 | 44 | 1.5 | 116 | 118 | 19 | 6.6 | 60 |
| Well #4 (4/27/48) | SE SW 12-T28N-R24E) | 336 | - | 52 | 5.3 | 152 | 150 | 18 | 9.5 | - |
| Well #5 (7/28/44) | NW NW NE 13-T29N-R21E | - | 8.1 | 20 | 11 | 95 | 308 | 42 | 132 | - |
| Well #6 4/28/48) | SE SW NW 23-T29N-R21E | 534 | - | 54 | 19 | 213 | 194 | 68 | 14 | - |

Oklahoma Water Resources Board, 1983, Tar Creek Field Investigation Task 1.4, "Groundwater Investigation in the Picher Field, Ottawa County, Oklahoma, 3/83.

## *Metals loading from Acid Mine Discharges*

**Table 26 (1994 Five-Year Review)**
*Metals Loading at Site 4s*
(tons/year)

| Constituent | 1980 – 1982 | 1987-1989 | Percent Change |
|---|---|---|---|
| Cadmium | 0.142 | 0.019 | - 659 |
| Iron | 383.7 | 169 | - 127 |
| Lead | 0.074 | 0.065 | - 14 |
| Sulfate | 3374.6 | 2169 | - 56 |
| Zinc | 252.7 | 61.7 | - 310 |
| Average | | | - 233 |

**Table 27 (1994 Five-Year Review)**
*Metals Loading at Site 14*
(Tons/Year)

| Constituent | 1980 – 1982 | 1987-1989 | Percent Change |
|---|---|---|---|
| Cadmium | 0.004 | 0.005 | + 19 |
| Iron | 172.3 | 122 | - 41 |
| Lead | 0.011 | 0.024 | + 118 |
| Sulfate | 994.8 | 1031.2 | + 4 |
| Zinc | 43.07 | 8.1 | - 434 |
| Average | | | - 67 |

**Table 28 (1994 Five-Year Review)**
*Metals Loading at Site 13 and 4L (1987-1989)*
(Tons/Year)

| Constituent | Site 13 | Site 4L |
|---|---|---|
| Cadmium | 0.013 | 0.015 |
| Iron | 45.7 | 81.1 |
| Lead | 0.027 | 0.075 |
| Sulfate | 835 | 2682 |
| Zinc | 8 | 62 |

**Table 29 (1994 Five-Year Review)**
*Metals Loading at Site 20 and Total Wiers Loading*
*(Tons/year)*

| Constituent | Stie 20 | Total Wiers | Fraction |
|---|---|---|---|
| Cadmium | 1.02 | 0.052 | 0.05 |
| Iron | 924 | 418 | 0.45 |
| Lead | 2.24 | 0.191 | 0.09 |
| Sulfate | 170,560 | 67,167 | 0.04 |
| Zinc | 1368 | 140 | 0.10 |
| Average | | | 0.15 |

## *Ground Water Monitoring*

## *Roubidoux Water Quality*

**Table 30 (1994 Five-Year Review)**
***Comparison of Mean Water Quality Parameters***

| *Well* | *Total Zinc (ug/L)* | | *Total Iron (ug/L)* | | *Sulfate (mg/L)* | |
|---|---|---|---|---|---|---|
| | *'92-'93* | *'96-'97* | *'92-'93* | *'96-'97* | *'92-'93* | *'96-'97* |
| Picher #2 | .1503 | .104 | .4411 | .374 | 122.0 | 183.1 |
| Picher #3 | .0645 | .05 | .4074 | .69 | 201.7 | 350 |
| Picher #4 | .1292 | .620 | .8938 | 1.975 | 289.2 | 331.8 |
| Quapaw #2 | .0448 | .079 | .9316 | 1.634 | 186.6 | 317 |
| Commerce #3 | .0505 | .038 | .3963 | .416 | 122.2 | 241 |

**Table 31** Water Quality Summary Statistics for 55 Roubidoux Wells (OWRB, 1983)

| Parameter | Number of Analyses | Maximum | Minimum | Mean |
|---|---|---|---|---|
| Temp, $^{o}$C | 97 | 27.7 | 13 | 20.6 |
| SC, umhos/cm | 118 | 1,564 | 262 | 610 |
| PH | 132 | 8.7 | 7.5 | 7.9 |
| Alkalinity, mg/L | 46 | 435 | 116 | 141.8 |
| Hardness, mg/L | 86 | 420 | 58 | 150 |
| Calcium, mg/L | 77 | 106 | 14 | 36 |
| Magnesium, mg/L | 77 | 38 | 3.2 | 15.3 |
| Sodium, mg/L | 58 | 320 | 4.4 | 59.5 |
| Potassium, mg/L | 62 | 6.2 | 1.1 | 2.89 |
| Chloride, mg/L | 95 | 387 | 2 | 100 |
| Sulfate, mg/L | 95 | 124 | 8 | 23 |
| Iron, ug/L | 45 | 810 | 20 | 108 |
| Lead, ug/L | 45 | 6 | 5 | 5 |
| Manganese, ug/L | 39 | 40 | 10 | 10 |
| Zinc, ug/L | 45 | 100 | 20 | 38 |
| TDS, mg/L | 67 | 824 | 126 | 299 |

Oklahoma Water Resources Board, 1983, Tar Creek Feasibility Investigation Task II.2.5.Ba-e, "Treatment of Roubidoux Water Supplies", October, 1983, p. 11.

**Table 32** Water Quality Summary Statistics for Roubidoux Wells in Northeast Ok (USGS, 1995)

| Parameter | Number of Analyses | Maximum | Minimum | 50$^{th}$ percentile |
|---|---|---|---|---|
| SC, umhos/cm | 96 | 125,000 | 140 | 566 |
| PH | 89 | 9.3 | 5.2 | 7.9 |
| Alkalinity, mg/L | 61 | 435 | 116 | 135 |
| Hardness, mg/L | 81 | 1,550 | 58 | 142 |
| Calcium, mg/L | 78 | 440 | 14 | 32 |
| Magnesium, mg/L | 78 | 110 | 1.1 | 14 |
| Sodium, mg/L | 73 | 3,200 | 1.4 | 54 |
| Potassium, mg/L | 71 | 25 | 0.4 | 2.8 |
| Chloride, mg/L | 93 | 65,000 | < 1 | 55 |
| Sulfate, mg/L | 94 | 2000 | 3 | 16 |
| Dis Iron, ug/L | 80 | 260,000 | < 8 | 60 |
| Lead, ug/L | 10 | 25 | < 5 | -- |
| Dis Manganese, ug/L | 80 | 4,400 | < 2 | 1.2 |
| Dis Zinc, ug/L | 81 | 84,000 | < 10 | 26 |
| TDS, mg/L | 86 | 113,000 | 88 | 290 |

Christenson, S., 1995, "Contamination of Wells completed in the Roubidoux Aquifer by Abandoned Zinc and Lead Mines, Ottawa County, Oklahoma", U.S. Geological Survey Water-Resources Investigations Report 95-4150, 114 pages.

**Table 33** Water Quality Summary Statistics for Roubidoux Wells in Picher Mining District (USGS, 1995)

| Parameter | Number of Analyses | Maximum | Minimum | 50th Percentile |
|---|---|---|---|---|
| SC, umhos/cm | 60 | 893 | 269 | 498 |
| pH | 60 | 8.03 | 6.95 | 7.44 |
| Alkalinity, mg/L | 60 | 190 | 116 | 138 |
| Calcium, mg/L | 120 | 120 | 26.8 | 51.45 |
| Magnesium, mg/L | 120 | 46.7 | 12.7 | 23 |
| Sodium, mg/L | 120 | 61.1 | 5.31 | 15.35 |
| Potassium, mg/L | 120 | 4.67 | < 0.45 | 2.51 |
| Chloride, mg/L | 80 | 87.2 | 4.55 | 19.35 |
| Sulfate, mg/L | 120 | 306 | 11.2 | 86.7 |
| Iron, ug/L | 120 | 1210 | < 6.1 | 310.5 |
| Lead, ug/L | 120 | 10.9 | < 1 | 1.66 |
| Manganese, ug/L | 120 | 18.7 | < 0.8 | 4.39 |
| Zinc, ug/L | 120 | 242 | < 1.3 | 17.2 |

Christenson, S., 1995, "Contamination of Wells completed in the Roubidoux Aquifer by Abandoned Zinc and Lead Mines, Ottawa County, Oklahoma", U.S. Geological Survey Water-Resources Investigations Report 95-4150, 114 pages.

**Table 34** Water Quality Summary Statistics for Background Roubidoux Wells (USGS, 1995)

| Parameter | Number of Analyses | Maximum | Minimum | 50th Percentile |
|---|---|---|---|---|
| SC, umhos/cm | 9 | 589 | 271 | 444 |
| pH | 9 | 7.94 | 7.59 | 7.83 |
| Alkalinity, mg/L | 9 | 134 | 116 | 124 |
| Calcium, mg/L | 18 | 161 | 28.2 | 31.9 |
| Magnesium, mg/L | 18 | 74.2 | 12.8 | 14.55 |
| Sodium, mg/L | 18 | 155 | 4.34 | 50.95 |
| Potassium, mg/L | 18 | 13.8 | < 0.44 | -- |
| Chloride, mg/L | 18 | 111 | 9.76 | 61.55 |
| Sulfate, mg/L | 18 | 147 | 10.9 | 13.3 |
| Iron, ug/L | 18 | 1320 | < 11 | -- |
| Lead, ug/L | 18 | 12.8 | < 1.4 | -- |
| Manganese, ug/L | 18 | 36.5 | < 1.7 | -- |
| Zinc, ug/L | 18 | 18.6 | < 3.2 | -- |

Christenson, S., 1995, "Contamination of Wells completed in the Roubidoux Aquifer by Abandoned Zinc and Lead Mines, Ottawa County, Oklahoma", U.S. Geological Survey Water-Resources Investigations Report 95-4150, 114 pages

Figure 12. Red line represents dissolved oxygen criterion for WWAC.

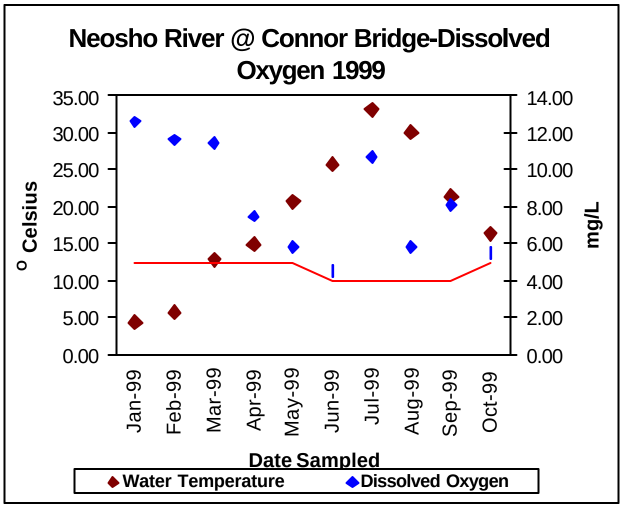



Figure 13. Red line represents upper (9.0) and lower (6.5) criterias.

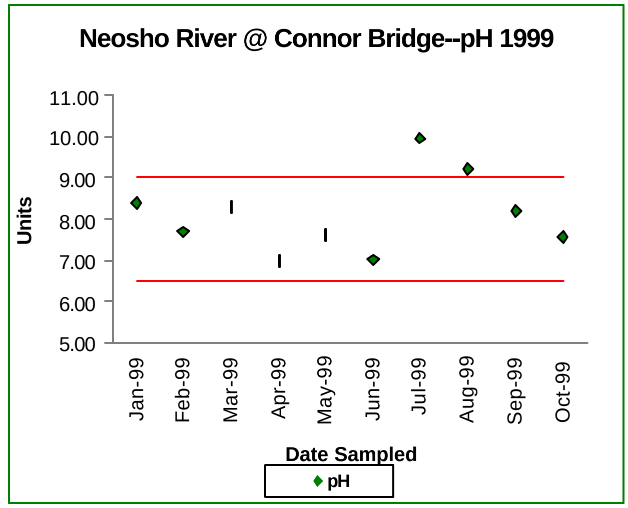



Figure 14. Red line represents turbidity criterion for WWAC.

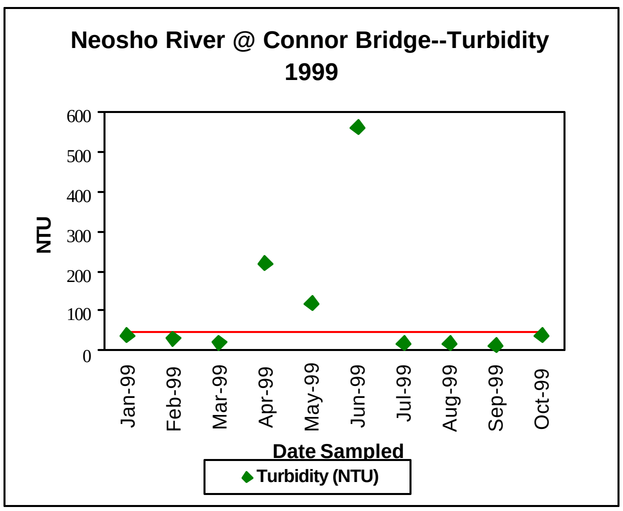



Figure 15. Red lines represent criteria for TDS (top), sulfate (middle), and chloride (bottom).

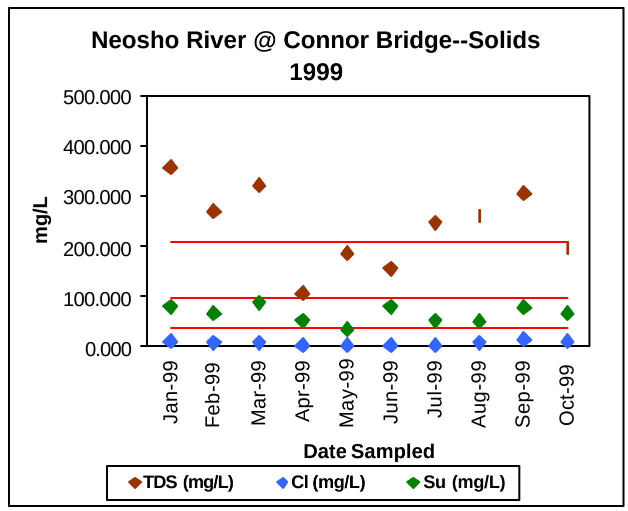



Figure 16. Red line represents screening level.

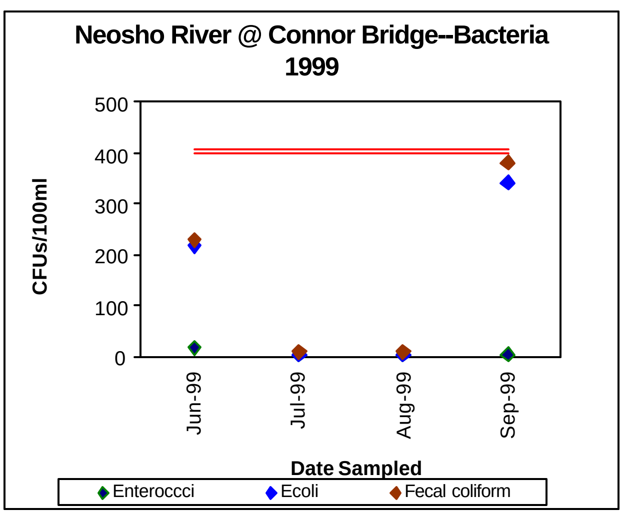



Figure 17. Red lines represent criteria for total phosphorus (bottom) and nitrate/nitrate (top).

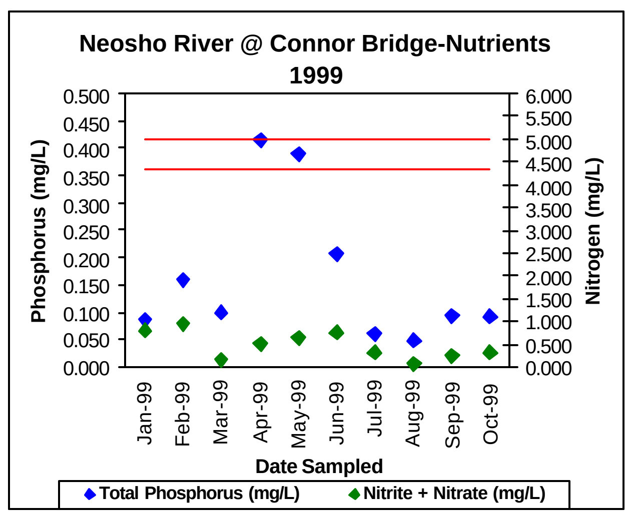


Figure 18. Red line represents dissolved oxygen criterion for CWAC.

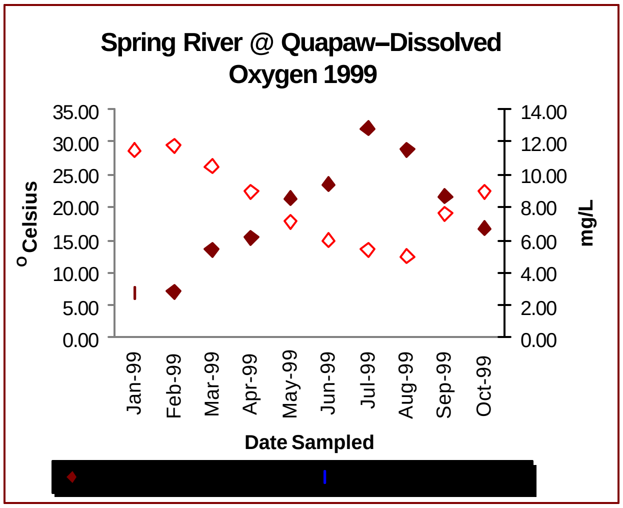



Figure 19. Red line represents upper (9.0) and lower (6.5) criterias.

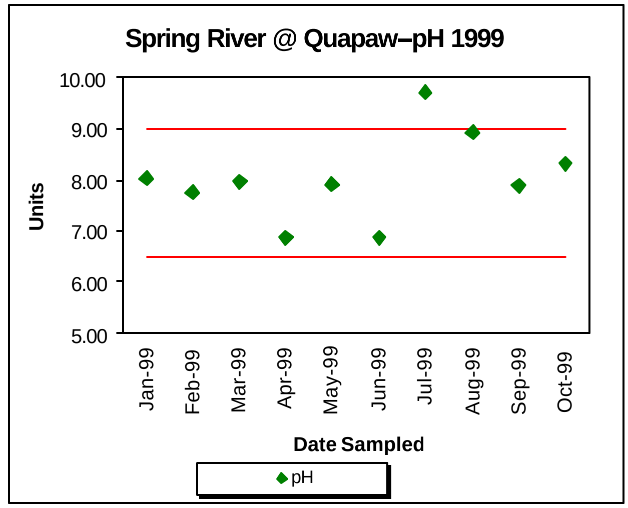



Figure 20. Red line represents turbidity criterion for CWAC.

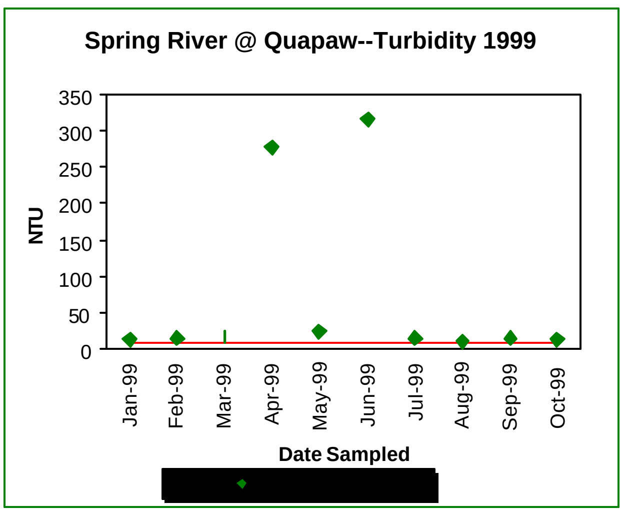



Figure 21. Red lines represent criteria for TDS (top), sulfate (middle), and chloride (bottom).

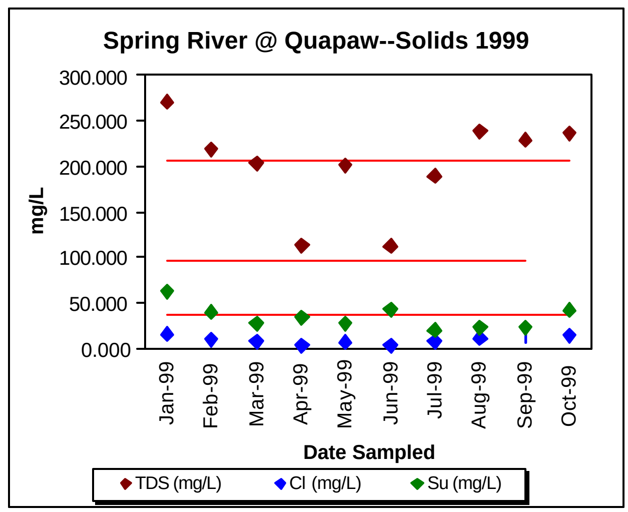



Figure 22. Red line represents screening level.

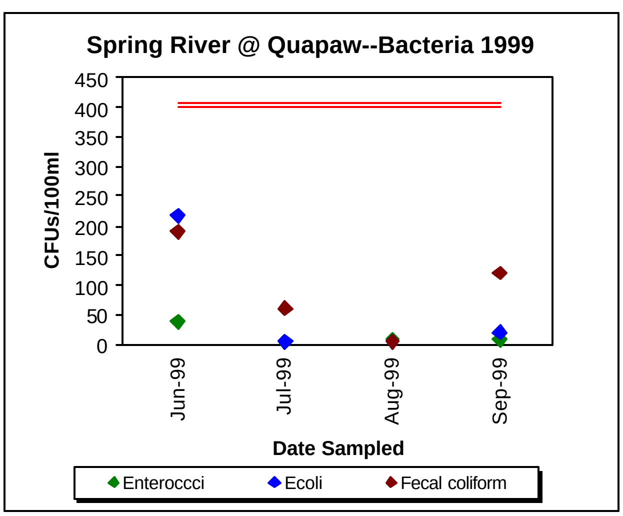
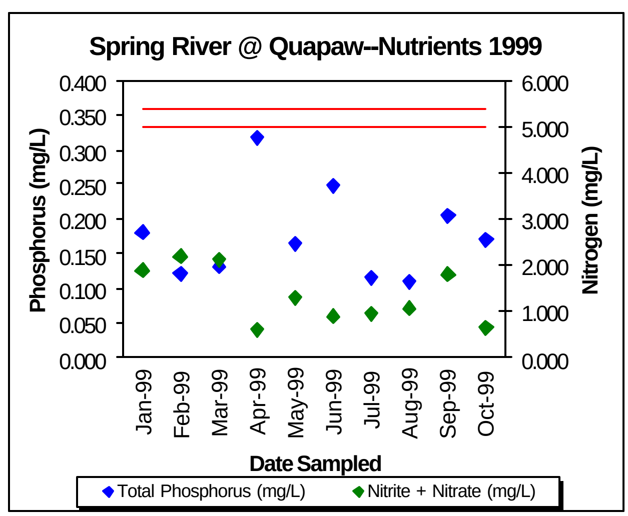



Figure 23. Red lines represent criteria for total phosphorus (top) and nitrate/nitrate (bottom).



# Appendix C
# Mine Shaft Monitoring Data

**Table 1**

*Statistical Summary of Selected Water Quality Data for Mine Shafts sampled during 1976 & 1977 (USGS, 1980)*

| *Parameter* | *# of Samples* | *Maximum* | *Minimum.* | *Mean* | *50th Percentile* |
|---|---|---|---|---|---|
| Alkalinity, (mg/L CaCO3) | 77 | 308 | 0 | 61 | 23 |
| Acidity (mg/L $CaCO_3$) | 66 | 1,340 | 0 | 465 | 320 |
| Hardness (mg/L $CaCO_3$) | 77 | 2,500 | 410 | 1,540 | 1,800 |
| pH | 147 | 8.6 | 3.4 | -- | 6.4 |
| Total Dis. Solids, (mg/L) | 74 | 5,920 | 622 | 4,000 | 3,410 |
| Specific Conductance, (umhos/cm) | 139 | 4,950 | 740 | 2,680 | 2,800 |
| Calcium, mg/L | 77 | 600 | 120 | 395 | 480 |
| Magnesium, mg/L | 77 | 290 | 13 | 133 | 134 |
| Arsenic, Total (ug/L) | 44 | 14 | 0 | 2.8 | 1.6 |
| Cadmium, Total (ug/L) | 77 | 1,100 | 10 | 310 | 180 |
| Iron, Total (ug/L) | 77 | 150,000 | 0 | 110,000 | 52,000 |
| Lead, Total (ug/L) | 77 | 500 | 0 | 220 | 310 |
| Manganese, Total(ug/L) | 77 | 15,000 | 10 | 3,370 | 2,400 |
| Sulfate (mg/L) | 77 | 3,500 | 320 | 1,950 | 2,070 |
| Zinc, Total (ug/L) | 74 | 490,000 | 730 | 108,000 | 106,000 |

Playton, S., Davis, R., and McClafin R., 1980, "Chemical Quality of Water in Abandoned Zinc Mines in Northeastern Oklahoma and Southeastern Kansas", Oklahoma Geological Survey, Circular 82, p. 37-39.

**Table 2**

Average Mine Shaft Water Quality of Samples (below SC gradient) taken in1980 – 1982 (OWRB, 1983)

| Parameters | Lawyer (2) | Kenoyer (3) | Consolidated #2 (3) | Admiralty #4 (1) |
|---|---|---|---|---|
| Temperature | 18.7 | 15.6 | 15.4 | 15.3 |
| PH | 4.55 | 5.53 | 5.03 | 5.4 |
| DO | 3 | 0.55 | 0.55 | 0.1 |
| SC, umhos/cm | 4,015 | 4,080 | 3,960 | 4,410 |
| Cadmium, ug/L | 255 | 95 | 71.3 | 82 |
| Iron, ug/L | 345,000 | 330,000 | 293,333 | 277,000 |
| Lead, ug/L | 59.5 | 63 | 121.3 | 80 |
| Zinc, ug/L | 205,500 | 194,667 | 106,300 | 331,000 |
| Sulfate, mg/L | 3,231 | 2,706 | 2,870 | 3,326 |

Admiralty #4: NE NW SW 29-T29N-R23E
Lawyer (New Chicago): SW SE NW 28-T29N-R23E
Kenoyer: NW NW SW 20-T29N-R23E
Consolidated #2: NE SW SE 16-T29N-R23E

Oklahoma Water Resources Board, 1983, Tar Creek Field Investigation Task 1.3, "Water Quality Assessment of the Flooded Underground mines of the Picher Field in Ottawa County, Oklahoma", March, 1983, p. 19.

Table 5

## Water Quality Data from Lucky Bill Air Shaft, April 1976-June 1977

| Date | Sampling Depth feet | Dissolved Sulfate mg/L | Dissolved Fluoride mg/L | Total Zinc ug/L | Dissolved Zinc ug/L | Total Iron ug/L | Dissolved Iron ug/L | Total Lead ug/L | Dissolved Lead ug/L | Total Cadmium ug/L | Dissolved Cadmium ug/L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4/22/76 | 178 | 810 | 0.3 | 68000 | 68000 | 350 | 290 | 450 | 250 | 180 | 9 |
| 4/22/76 | 210 | 2800 | 5 | 350000 | 280000 | 160000 | 150000 | 300 | 69 | 400 | 420 |
| 4/22/76 | 222 | 3000 | 9.2 | 480000 | 490000 | 290000 | 270000 | 500 | 400 | 460 | 490 |
| 8/26/76 | 205 | 320 | 0.3 | 20000 | 20000 | 380 | 370 | 100 | 90 | 70 | 10 |
| 8/26/76 | 228 | 3400 | 9.4 | 470000 | 450000 | 350000 | 330000 | 400 | 400 | 380 | 370 |
| 10/20/76 | 190 | 380 | 0.7 | 46000 | 25000 | 80 | 20 | 200 | 150 | 80 | 12 |
| 10/20/76 | 225 | 3500 | 7.5 | 440000 | 440000 | 370000 | 240000 | 300 | 350 | 350 | 330 |
| 12/7/76 | 190 | 430 | 0.1 | 27000 | 27000 | 150 | 150 | 200 | 97 | 100 | 13 |
| 12/7/76 | 225 | 3100 | 6.6 | 430000 | 420000 | 340000 | 2700000 | 300 | 200 | 380 | 360 |
| 2/17/77 | 190 | 510 | 1.2 | 36000 | 35000 | 170 | 70 | <100 | 98 | 110 | 10 |
| 2/17/77 | 225 | 3300 | 7.4 | 420000 | 410000 | 320000 | 300000 | 300 | 250 | 330 | 340 |
| 4/21/77 | 190 | 610 | 0.4 | 49000 | 49000 | 240 | 60 | 400 | 150 | 600 | 140 |
| 4/21/77 | 225 | 3500 | 7.9 | --- | 412000 | 320000 | 290000 | 300 | 250 | 310 | 340 |
| 6/7/77 | 155 | 420 | 0.2 | 39000 | 39000 | 180 | 20 | 200 | 99 | 110 | 8 |
| 6/7/77 | 225 | 3400 | 7.9 | 440000 | 440000 | 320000 | 310000 | 300 | 250 | 300 | 350 |

## Water Quality Data from Birthday Mine Shaft, April 1976-June 1977

| Date | Sampling Depth feet | Dissolved Sulfate mg/L | Dissolved Fluoride mg/L | Total Zinc ug/L | Dissolved Zinc ug/L | Total Iron ug/L | Dissolved Iron ug/L | Total Lead ug/L | Dissolved Lead ug/L | Total Cadmium ug/L | Dissolved Cadmium ug/L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4/23/76 | 166 | 3000 | 8.1 | 470000 | 490000 | 110000 | 110000 | 300 | 79 | 880 | 900 |
| 4/23/76 | 185 | 3000 | 7.2 | 490000 | 490000 | 110000 | 10000 | 300 | 93 | 900 | 900 |
| 8/25/76 | 160 | 520 | 0.4 | 9200 | 9400 | 240 | 210 | <100 | 12 | 60 | 60 |
| 8/25/76 | 180 | 2100 | 2.9 | 340000 | 260000 | 110000 | 89000 | 300 | 40 | 270 | 230 |
| 10/19/76 | 162 | 1000 | 1.8 | 65000 | 65000 | 15000 | 13000 | 100 | 51 | 130 | 8 |
| 10/19/76 | 180 | 3100 | 2.5 | 370000 | 360000 | 150000 | 110000 | 200 | 13 | 100 | 60 |
| 12/7/76 | 160 | 870 | 0.5 | 54000 | 4400 | 2000 | 710 | 100 | 2 | <10 | 1 |
| 12/7/76 | 180 | 3500 | 1.1 | 390000 | 390000 | 160000 | 73000 | 300 | 67 | 160 | 60 |
| 2/18/77 | 160 | 2900 | 8.6 | 340000 | 340000 | 190000 | 180000 | 300 | 300 | 350 | 360 |
| 2/18/77 | 180 | 3200 | 6.5 | 390000 | 380000 | 210000 | 200000 | 300 | 300 | 360 | 370 |
| 4/21/77 | 155 | 760 | 1.1 | 8400 | 8300 | 280 | 140 | 100 | 50 | 130 | 140 |
| 4/21/77 | 170 | 2700 | 7.6 | 310000 | 270000 | 190000 | 170000 | 300 | 200 | 280 | 300 |
| 4/21/77 | 180 | 3100 | 1.2 | 410000 | 370000 | 200000 | 200000 | 200 | 200 | 100 | 80 |
| 6/8/77 | 155 | 360 | 0.6 | 6400 | 6700 | 710 | 90 | <100 | 7 | 60 | 55 |
| 6/8/77 | 170 | 3200 | 8.6 | 340000 | 340000 | 240000 | 220000 | 200 | 40 | 260 | 180 |
| 6/8/77 | 180 | 3200 | 0.4 | 410000 | 400000 | 230000 | 230000 | 300 | 17 | 80 | 20 |

Table 6

**Water Quality Data from Lucky Jew Mine Shaft, April 1976-June 1977**

| Date | Sampling Depth feet | Dissolved Sulfate mg/L | Dissolved Fluoride mg/L | Total Zinc ug/L | Dissolved Zinc ug/L | Total Iron ug/L | Dissolved Iron ug/L | Total Lead ug/L | Dissolved Lead ug/L | Total Cadmium ug/L | Dissolved Cadmium ug/L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4/27/76 | 200 | 560 | 0.3 | 830 | 640 | 0 | 20 | <100 | 6 | 10 | 4 |
| 4/27/76 | 222 | 1200 | 1.3 | 3000 | 2900 | 52000 | 44000 | <100 | 7 | <10 | 4 |
| 4/27/76 | 230 | 1300 | 2.1 | 9300 | 8100 | 52000 | 50000 | <100 | 2 | <10 | 2 |
| 4/27/76 | 298 | 1300 | 2.1 | 10000 | 8300 | 53000 | 46000 | <100 | 4 | <10 | 6 |
| 10/21/76 | 200 | 520 | 0.6 | 730 | 670 | 160 | 10 | <100 | 3 | 10 | 4 |
| 10/21/76 | 220 | 1400 | 2.2 | 7000 | 7000 | 58000 | 57000 | 100 | 4 | 10 | 1 |
| 6/9/77 | 200 | 600 | 0.3 | 2300 | 2300 | 30 | 30 | <100 | 6 | 10 | 8 |
| 6/9/77 | 220 | 1300 | 2.1 | 7000 | 6600 | 61000 | 54000 | 100 | 4 | 10 | 2 |

**Water Quality Data from Lavrion Mine Shaft, April 1976**

| Date | Sampling Depth feet | Dissolved Sulfate mg/L | Dissolved Fluoride mg/L | Total Zinc ug/L | Dissolved Zinc ug/L | Total Iron ug/L | Dissolved Iron ug/L | Total Lead ug/L | Dissolved Lead ug/L | Total Cadmium ug/L | Dissolved Cadmium ug/L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4/28/76 | 160 | 2500 | 9.8 | 340000 | 390000 | 67000 | 76000 | 300 | 20 | 980 | 10 |
| 4/28/76 | 182 | 2900 | 15 | 420000 | 420000 | 140000 | 130000 | 300 | 16 | 860 | 13 |
| 4/28/76 | 191 | 2700 | 14 | 440000 | 430000 | 160000 | 130000 | 200 | 10 | 830 | 13 |

**Water Quality Data from Skelton Mine Shaft, April 1976-June 1977**

| Date | Sampling Depth feet | Dissolved Sulfate mg/L | Dissolved Fluoride mg/L | Total Zinc ug/L | Dissolved Zinc ug/L | Total Iron ug/L | Dissolved Iron ug/L | Total Lead ug/L | Dissolved Lead ug/L | Total Cadmium ug/L | Dissolved Cadmium ug/L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4/26/76 | 165 | 1300 | 1.8 | 59000 | 47000 | 8900 | 140 | 100 | 1 | 160 | 9 |
| 10/18/76 | 160 | 1600 | 2.9 | 110000 | 110000 | 29000 | 28000 | 200 | 30 | 490 | 470 |
| 6/6/77 | 165 | 2300 | 2.3 | 250000 | 250000 | 70 | 60 | 200 | 350 | 1100 | 1200 |

**Table 7** **Water Quality Data from Consolidated No. 2 Mine Shaft, April 1976-June 1977**

| Date | Sampling Depth feet | Dissolved Sulfate mg/L | Dissolved Fluoride mg/L | Total Zinc ug/L | Dissolved Zinc ug/L | Total Iron ug/L | Dissolved Iron ug/L | Total Lead ug/L | Dissolved Lead ug/L | Total Cadmium ug/L | Dissolved Cadmium ug/L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4/20/76 | 191 | 460 | 0.3 | 3000 | 3200 | 650 | 0 | <100 | 2 | 80 | 90 |
| 4/20/76 | 227 | 520 | 0.4 | 4900 | 400 | 800 | 670 | <100 | 2 | 100 | 100 |
| 4/21/76 | 229 | 3100 | 1.9 | 280000 | 310000 | 250000 | 130000 | 300 | 200 | 780 | 780 |
| 4/21/76 | 234 | 3200 | 1.6 | 360000 | 380000 | 510000 | 130000 | 500 | 400 | 950 | 930 |
| 8/25/76 | 165 | 360 | 0.4 | 2200 | 2200 | 120 | 80 | <100 | 10 | 110 | 110 |
| 8/25/76 | 230 | 1600 | 1.7 | 300000 | 150000 | 290000 | 210000 | 400 | 200 | 620 | 360 |
| 10/19/76 | 1685 | 440 | 0.7 | 3900 | 3900 | 140 | 40 | 100 | 3 | 90 | 80 |
| 10/19/76 | 230 | 3400 | 2.4 | 290000 | 290000 | 300000 | 310000 | 300 | 300 | 570 | 540 |
| 12/7/76 | 165 | 490 | 0.3 | 30000 | 3500 | 70 | 40 | <100 | 3 | 90 | 70 |
| 12/7/76 | 230 | 3500 | 1.9 | 280000 | 280000 | 300000 | 290000 | 300 | 350 | 540 | 540 |
| 2/17/77 | 165 | 510 | 0.5 | 330000 | 3300 | 120 | 0 | <100 | 1 | 60 | 65 |
| 2/17/77 | 230 | 3300 | 3.5 | 300000 | 300000 | 310000 | 300000 | 400 | 450 | 580 | 600 |
| 4/21/77 | 165 | 500 | 0.6 | . | 4200 | 480 | 40 | 100 | 50 | 70 | 75 |
| 4/21/77 | 230 | 3000 | 1.5 | . | 292000 | 280000 | 270000 | 400 | 400 | 580 | 610 |
| 6/7/77 | 165 | 370 | 0.4 | 2100 | 2100 | 300 | 70 | 0 | 0 | 70 | 80 |
| 6/7/77 | 230 | 3100 | 1.8 | 310000 | 310000 | 350000 | 53000 | 400 | 350 | 530 | 550 |

**SUMMARY**

**of the**

**PUBLIC WATER SUPPLY SYSTEMS**

**in the**

**TAR CREEK AREA**

Prepared by
Water Quality Division
Oklahoma Department of Environmental Quality

Information Compiled by
Richard L. Brooks, PWS District Representative

**July 25, 2000**

## *Introduction*

In order to determine the general quality and characteristics of the groundwater in the Tar Creek mining area of Oklahoma, an evaluation of the historical data and information available related to the public water supplies serving communities in the area was conducted.

As a result of this evaluation, a reasonably clear picture of the area's groundwater can be described. The quality of the groundwater has been impacted by past mining activities and public water supplies have also reflected this degradation. While the quality of the groundwater has decreased, there are few instances of public water supplies being in violation of the Federal Safe Drinking Water Act because of contamination due to these past mining activities. However, some of the water used for public water supplies is aesthetically undesirable, with exceedance of secondary standards, all attributable to past mining activities.

### *Surface and Ground Water Impacts*

Lead and zinc mining in the Tar Creek area of northeastern Oklahoma, has resulted in conditions of degraded surface and ground water quality. Seventy years of extensive mining within the water bearing Boone Formation ceased in 1970. Some mining ("scavenging") continued to a much lesser degree until 1981. Water has since filled the abandoned shafts and now discharges to the surface. This water is highly mineralized from exposure to lead and zinc sulfide ores and pyrite ($FeS_2$) which produce acid. The acid reacts with carbonate minerals in the ores to produce an alkaline solution. When this mineralized water surfaces, it reacts with oxygen in air causing metals to precipitate and the water to become acidic.

Mineralized waters in the Boone formation pose a threat to water in the underlying Roubidoux aquifer. Public water supply wells in the Tar Creek area are cased through the Boone formation and completed in the Roubidoux aquifer. Several public water wells have been plugged due to introduction of mineralized Boone water into the well via the following pathways:

- Failure of the well casing caused by corrosive water,
- Migration down the thin annular space between casing and the well bore,
- Downward migration through porous geologic formations between the abandoned mines and the Roubidoux formation.
- Man-made breaches such as boreholes in an permeable geological barriers between the Boone and Roubidoux formations.

### *Aquifers*

The Boone Formation, which is generally within 10 to 75 feet of the surface in the Tar Creek area, consists of 350 to 400 feet of limestone and chert. Groundwater movement is primarily through fractures and solution cavities. It is considered to be a good source of quality water outside the mining area.

The Roubidoux Formation, which is generally within 950 to 1,000 feet of the surface in the Tar Creek area, consists of 105 to 180 feet of cherty dolomite with two or three layers of sandstone 15 to 30 feet thick. It is a major producer of groundwater in the area, with a yield of up to 600 gpm. Most of the water is produced from a few relatively thin, highly permeable, sandstone zones.

***Superfund***

EPA began studying the environmental impacts of mine drainage in 1979. The Tar Creek area was proposed as a Superfund site for the National Priorities List (NPL) in 1981, and added to the NPL in 1983. Remedial activities were conducted to mitigate mine water impacts to surface and groundwater. These remedial activities included diversion of surface water to prevent it entering abandoned mines and plugging 83 abandoned water wells to prevent mine waters in the Boone Formation from infiltrating the lower Roubidoux aquifer.

The DEQ is currently conducting "After Action Monitoring" of the site to determine if the Remedial Actions have improved water quality or if more corrective action and other approaches are warranted. Phase I of the Tar Creek Ground Water Monitoring Project consisted of the collection and analysis of water samples from eleven (11) Roubidoux water supply wells inside the mining area and ten (10) Roubidoux wells outside the mining area. The results of the public water supply monitoring caused water quality to be suspect in five (5) of the PWS wells inside the mining area. These wells produce water with concentrations of iron, zinc, and sulfate elevated over concentrations found in the Roubidoux aquifer outside the mining area. Phase I was conducted from 1990 through 1991.

Phase II of the Monitoring Project will determine which pathways contribute to the poor quality of drinking water. Discrete water samples from the five municipal wells and the monitoring well, continue to be collected for analysis and evaluation. Also, in the Phase II Supplement of the Project, four more monitoring wells are to be developed in the Roubidoux aquifer for the collection of groundwater samples. To establish representative Roubidoux monitoring sites, the wells will be constructed to the specifications of typical public water supply wells.

***Private Water Systems***

The 1990 U.S. Census projected a total population of 32,460 in Ottawa County and estimated that 10,385 (approximately one-third) would live outside of towns. It is unknown how many of the County's rural population actually resides in the Tar Creek area; however, it is reasonable to assume that the rural population in the Tar Creak Area may be between 1,500 to 3,000. It is suspected that many of the rural residents are served by private wells, produced either in the Boone or Roubidoux aquifers. Therefore, there is a potential that these private wells are being impacted by contamination in the Boone or being conduits for contamination of the Roubidoux.

***Communities and their Public Water Supplies***

The Tar Creek area includes 40 square miles in Ottawa County in Oklahoma and affects the towns of Quapaw, Commerce, Picher, North Miami and Cardin. North Miami purchases water from Miami which utilizes wells located outside the mining area (see Table 1). Below shows the public water supply production in the Tar Creek area.

*Table 1*

| System/ Well # | Well Status | Present Monthly Usage (Gallons) | % Usage | Current Population Served |
|---|---|---|---|---|
| **Cardin** | | | | |
| 1 | Primary | 672,000 | 100 | 310 |
| | System's Total Usage → | 672,000 | | |
| **Commerce** | | | | |
| 1 | Secondary | 1,519,538 | 20.9 | 2,526 |
| 2 | Secondary | 1,508,524 | 20.7 | |
| 3 | Inactive | N/A | | |
| 4 | Primary | 4,248,000 | 58.4 | |
| | System's Total Usage → | 7,276,062 | | |
| **Quapaw** | | | | |
| 1 | Inactive | N/A | | 947 |
| 2 | Standby | 0 | 0.0 | |
| 3 | Plugged | N/A | | |
| 4 | Primary | 6,558,000 | 100 | |
| | System's Total Usage → | 6,558,000 | | |
| **Picher** | | | | |
| 1 | Plugged | N/A | | 1,814 |
| 2 | Secondary | 1,232,000 | 2.4 | |
| 3 | Standby | 0 | 0.0 | |
| 4 | Inactive | N/A | | |
| 5* | Primary | 50,000,723 | 97.6 | |
| | System's Total Usage→ | 51,232,723 | | |
| | **Grand Total →** | **65,738,785** | --- | **5,597** |

* - Superfund monitoring well installed during Phase II, prior to the Phase II - Supplemental Project.

N/A – not applicable

### *Water Quality*

Based on Phase I of the Tar Creek Ground Water Monitoring Project, DEQ and EPA concluded that the five public water wells were producing water exceeding secondary drinking water standards of iron, sulfate and zinc, and that these wells were impacted by corrosive mine water. However, these wells do not pose a health threat. Secondary standards represent aesthetic guidelines (taste, odor, and color) for drinking water quality and are not federally or State enforceable.

Table 2 below presents the range of historical analytical results collected between 1985 and 1996 by the DEQ for each of the (older) active, inactive and plugged public water supply wells in the Tar Creek area. The Picher #5 well, a Superfund well installed in 1997 during Phase II (prior to the Phase II – Supplemental Project), meets the Secondary Maximum Concentration Level (SMCL) for iron, zinc, and sulfate. The extremely high values seen are very well due to inadequate line flushing prior to sample collection. Exclusion of the highest values seen for the older wells brings the data much closer to those reported for the Picher #5 well and reported by the USGS for the same wells. As proposed for the Phase II – Supplemental Project, Picher #5 is cased and grouted down to the Roubidoux Formation.

***Table 2***

| System /Well # | Present Well Status | Parameter (mg/L) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Iron | | Manganese | | Zinc | | Sulfate | |
| | | Min | Max | Min | Max | Min | Max | Min | Max |
| **Cardin** | | | | | | | | | |
| 1 | Primary | BDL | 0.37 | BDL | 0.01 | BDL | 0.45 | BDL | 228 |
| **Commerce** | | | | | | | | | |
| 1 | Secondary | 0.13 | 0.15 | BDL | BDL | 0.19 | 1.84 | 80 | 262 |
| 2 | Secondary | 0.03 | 0.46 | BDL | BDL | BDL | 0.34 | BDL | 286 |
| 3 | Inactive | 0.10 | 0.50 | BDL | 0.01 | 0.01 | 0.45 | BDL | 119 |
| 4 | Primary | BDL | 1.34 | BDL | 0.02 | BDL | 0.72 | BDL | 208 |
| **Quapaw** | | | | | | | | | |
| 1 | Inactive | ND | ND | ND | ND | ND | ND | ND | ND |
| 2 | Standby | BDL | 3.34 | BDL | 0.09 | BDL | 1.36 | BDL | 566 |
| 3 | Plugged | ND | ND | ND | ND | ND | ND | ND | ND |
| 4 | Primary | BDL | 0.97 | BDL | 0.02 | BDL | 0.54 | BDL | 264 |
| **Picher** | | | | | | | | | |
| 1 | Plugged | 0.20 | 25.90 | BDL | 0.67 | BDL | .16 | BDL | 152 |
| 2* | Secondary | BDL | 29.97 | BDL | 0.11 | BDL | 25.18 | BDL | 1,000 |
| 3 | Standby | BDL | 6.92 | BDL | 0.04 | BDL | 0.66 | BDL | 492 |
| 4 | Inactive | 0.12 | 1.22 | BDL | 0.03 | 0.01 | 11.61 | 34 | 1,073 |
| 5 | Primary | 0.07 | 0.23 | ND | ND | BDL | BDL | 25 | 197 |
| | **SMCL ®** | | **0.3** | | **0.05** | | **5** | | **250** |

ND – no data
BDL – below detection limits of 5 - 10 μg/l for zinc, iron and manganese and 20 μg/l sulfate.
*quality has improved since inflatable packer was installed in 1996.

***Regulatory Compliance***

None of these systems are presently under enforcement action from DEQ as there are no violations of Maximum Contaminant Levels (MCL). Commerce and Quapaw facilities were most recently inspected on July 5, 2000. A follow-up inspection of the Commerce facility is tentatively scheduled for August 1st. A routine inspection of Picher and Cardin is tentatively scheduled for August 2nd.

***Options***

In 1996, all of the public water systems serving the communities of the Tar Creek area (including Miami and North Miami) considered organizing one rural water district using surface water for a source. Spring River would have been the supply for a surface water treatment plant. These systems also considered but did not join a water district being formed in 1995 that utilized a surface water treatment plant located in Baxter Springs, Kansas, which began operations in 1997.

The communities opted to use five (5) wells to be funded solely by the Superfund Ground Water Monitoring Project. These 8-inch diameter monitoring wells are designed to meet PWS requirements. They are cased through the Boone aquifer and mine workings down to the Roubidoux aquifer. Table 3 reflects the current status of Phase II of this project.

***Table 3***

| System | Present Phase II Project Status |
|---|---|
| Cardin | Picher-Cardin #7, located just outside Picher's incorporated boundaries is being drilled, to be operated by Picher and to be available to Cardin as a standby source. |
| Commerce | Commerce #5 has been recently drilled with pump and power installed.<br><br>Plugging of Commerce #3, an inactive well, is pending. |
| Quapaw | Quapaw #5 has been recently drilled with pump installed.<br>Power installation is pending.<br><br>Plugging of Well #1, an inactive well, is pending. |

| | |
|---|---|
| | |
| Picher | Picher #6 (with intermediate piping) has been recently drilled.<br>Pump and power installation is pending.<br><br>Picher-Cardin #7 is being drilled and intermediate piping will be needed.<br><br>Plugging of Picher #3 (standby well) and #4 (inactive well) are pending. |

***Future Activities***

The Phase II Project will install four (4) additional monitoring wells in the Roubidoux aquifer for the collection of groundwater samples. The wells will be constructed to the specifications typical for public water supply wells of the area. This will allow the option of the wells being used for drinking water supplies should the water quality of the wells prove to be acceptable.

If all wells produce good quality water this would eliminate reliance on older wells by the end of the summer of 2000.

***Potential Problems/Set-backs***

The Phase II project is 90 percent federally funded in combination with 10 percent state matching funds. There is a possibility that funds from either source will be postponed, reduced or eliminated; however, drilling activities are almost completed. The allocation of funds to plug the Quapaw Well #1 well is pending. Additional well plugging is to be conducted with “in-house” funding.

***Summary***

The Boone Formation has become contaminated as much of the past mining activities were conducted within the confines of this aquifer. As the contaminated water of the Boone Formation reached the surface, the resultant acid mine drainage reaching the streams and rivers had a profound impact not only on the aesthetics of the streams and rivers, but also impacted the flora and fauna which would normally been present as diverse species and in substantial quantities.

The Roubidoux aquifer is strongly suspected of being impacted via intrusion through cracks, fissures, and/or corroded well casings by the Boone aquifer contaminated with iron, manganese, zinc and sulfate. This can be substantiated by comparing monitoring data of the recently installed Superfund/PWS well to those from older PWS wells in the Tar Creek area. The impact of the Roubidoux aquifer has resulted in communities abandoning existing PWS wells and seeking other supplies of better quality.